Aptian-turonian events in central Tunisia : [pre-symposium field trip]

Annie Arnaud Vanneau, Ihsen Zghal

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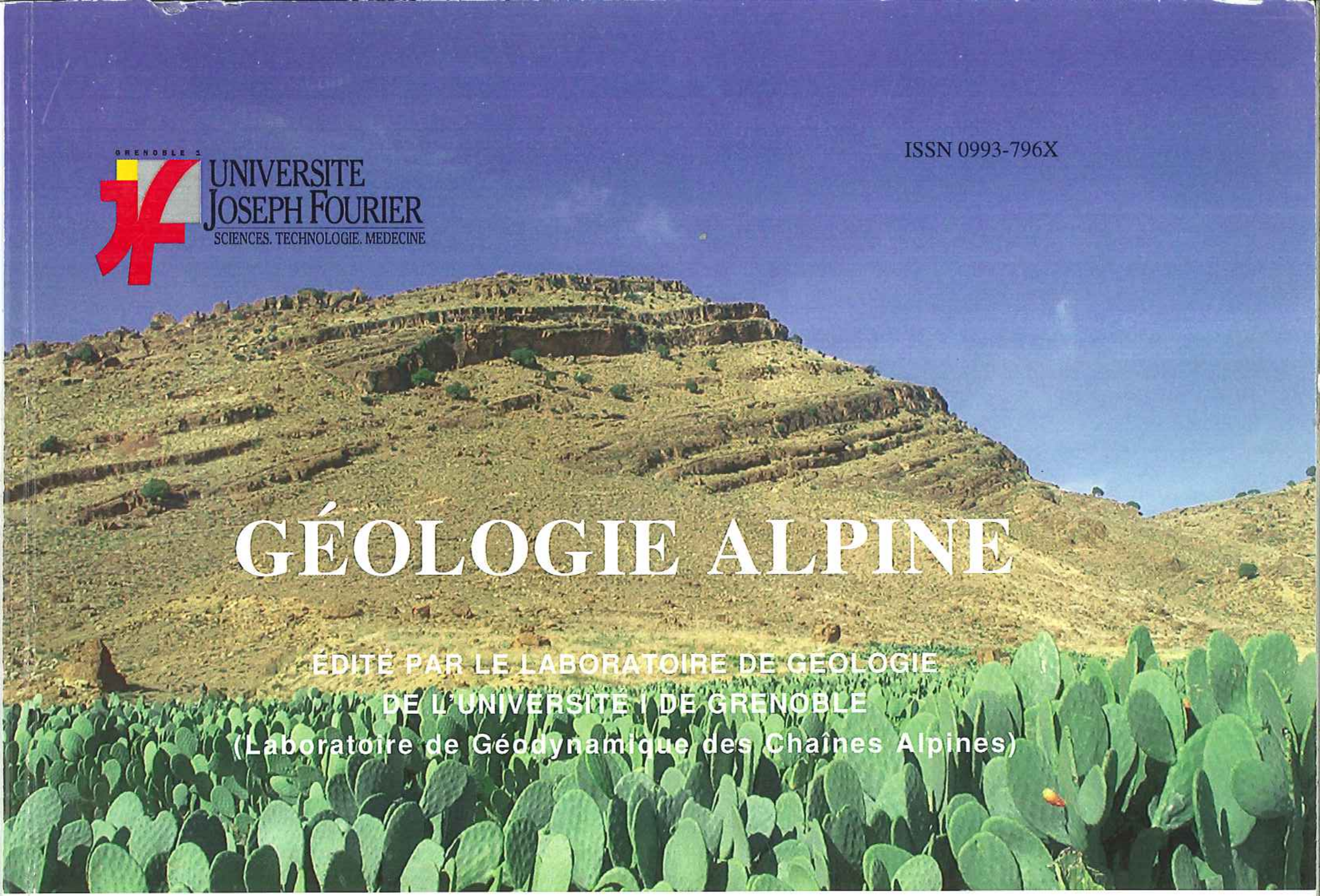

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(Laboratoire de Géodynamique des Chaînes Alpines)

SÉRIE SPÉCIALE «COLLOQUES ET EXCURSIONS» N° 5

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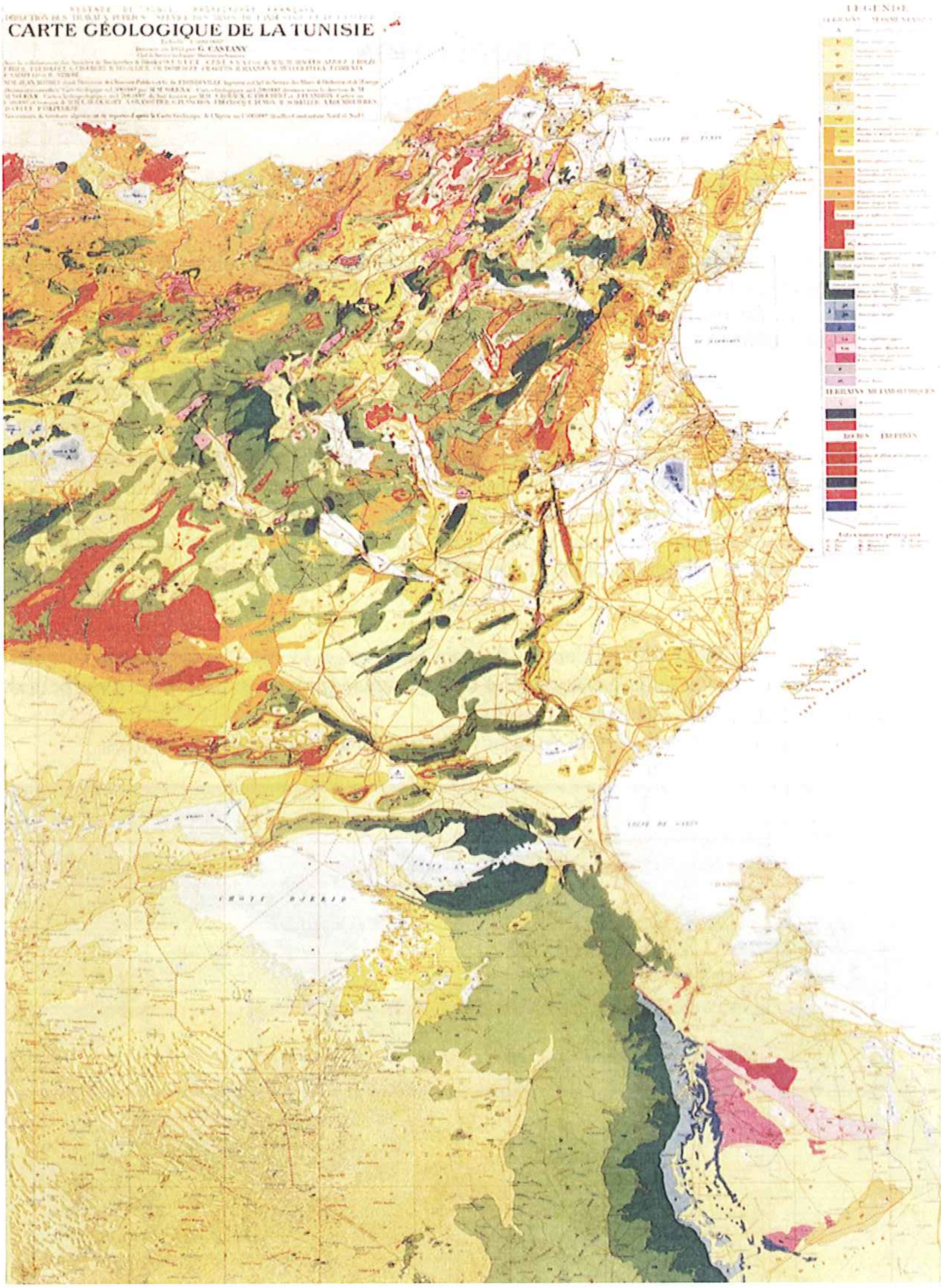

Fig. A1 – Geological map of Tunisia (Congrès géologique d'Alger,1950).

INTRODUCTION

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The central part of Tunisia is formed by anticlines, the axis of which are oriented SW-NE. These mountains, called Jebel, are separated by alluvial plains. The mountains consist usually of folded and faulted Aptian carbonate platform (Serdj Fm), surrounded by Albian shales and Cenomanian-Turonian marls and limestones. These lithologic contrasts controlled the landscape: massive Aptian or Turonian limestone form cliffs and ridges, while valleys and lowlands are caved in Albian-Turonian shales and marls.

This pre-symposium field trip in Central Tunisia is devoted to the Upper Aptian-Turonian succession which records sedimentologic and tectonic episodes related to this peculiar period. Several noteworthy events occurred at that time.

1) Opening of South and Central Atlantic Ocean and increasing plate velocities,

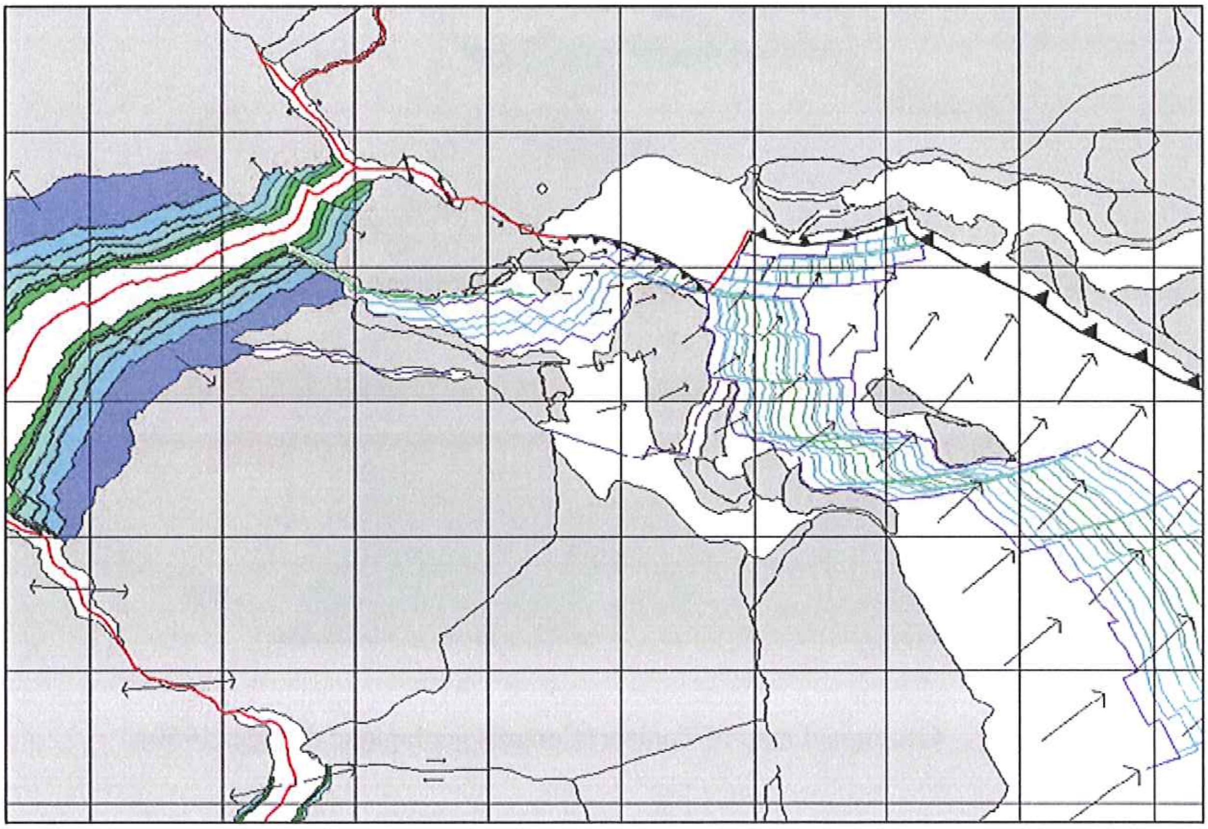

Fig. A2 - Reconstruction at110.0 Ma (Lower Albian). Vectors represent direction and magnitude of the relative velocity field between conjugate pairs of plates. Blue lines represent the modeled 172.0 Ma, 170.0 Ma, M25, M21, M16 and M10 isochrons. The 130.0 Ma, M4 and M0 isochrons are indicated in green. The location of the Euler pole of relative convergence between Northeast Africa and Eurasia is marked by a small empty circle. (Schettino, A. and Scotese, C. 2002)

The first important feature of this time period is represented by the onset of seafloor spreading in South Atlantic, and by the opening of the Biscay Bay [Srivastava et al., 1990].Spreading rates were high in the South Atlantic (~43 mm/yr at the Romanche Fracture Zone and ~63 mm/yr at the Agulhas-Falkland Shear Zone) and the Central Atlantic (55 mm/yr in the southernmost region). Simultaneously, the African plate experienced internal deformations expressed by the onset of right-lateral motion along the Central African Shear Zone and rifting episodes in the Benue Trough and Termit Basins [Wilson and Guiraud, 1992 ; Genik, 1992 ; Guiraud and Maurin, 1992]. (Schettino, A. and Scotese, C. 2002).

2) Establishment of new North-South oceanic current circulation.
3) Rapid and important sea level changes.

This field trip is focused on 3 areas located between El Kef and Kasserine, close to the Algerian border. The two first days, the Jebel El Hamra and Jebel Hameima allow to examine a part of the Upper Aptian carbonate platform succession (Serdj Fm), the demise of the carbonate platform, karstification and mineralization, the upper Aptian to lower Albian tectonic episodes and the Albian anoxic events.
The third day will be devoted to the Cenomanian-Turonian series and examination of records of sea level changes and anoxia in basinal deposits.

The organisation of this field trip is the culmination of 3-year collaboration between a Tunisian team of the University of Sfax and a French team of the University of Grenoble. The project CMCU n° 02F1006 "Les Paléo-environnements des bassins crétacés de l'Atlas saharien de Tunisie. Évolution sédimentaire, diagenétique et géodynamique, interactions évènements climatiques globaux/eustatisme/tectonique". " has been led by Ihsen Zghal in Sfax and Annie Arnaud Vanneau in Grenoble. The organizers of this field trip are as follows in alphabetic order.

Carbonate platform: Annie Arnaud Vanneau, Abir Echihaoui, Jamel Touir, Ihsen Zghal
Tectonics: Hubert Arnaud, Thierry Dumont, Moncef Feki, Claude Gourmelen, Jamel Ouali, Adel Rigane
Albian shales and marls: Abir Echihaoui, Etienne Jaillard, Jean Louis Latil, Jamel Touir, Ihsen Zghal.

The Cenomanian-Turonian succession will be presented independently of this project. The organizers are grateful to Francis Robazinsky from Mons (Belgium) for having accepted to present the results of a long-termed and acknowledged study of the Late Cretaceous succession of central Tunisia.

Fig. A3 – Geographic map of Tunisia showing the main stops. Day 1 ; Tunis-El Kef. Day 2, EL-Kef-Jebel El Hamra-El Kef. Day 3 : El Kef-Tadjerouine-Djebel Hameïma-El Kef. Day 4 : El Kef-Tdjerouina-Oued Smarra-El Kef-Tunis. Day 5 : Tunis and departure to France.

STRUCTURAL AND PALEOGEOGRAPHIC EVOLUTION IN CENTRAL TUNISIA IN THE CRETACEOUS

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INTRODUCTION: STRUCTURAL FRAMEWORK OF TUNISIA

Tunisia belongs to the eastern part of the Maghreb (Fig.1). It is geologically located in the Sahara southern domain belonging to the old African craton, and a more mobile domain structured by the alpine orogeny that lies over the Center and the North of the country while forming the Tunisian Atlas. The geodynamic history of Tunisia is, therefore, largely bound to the relative displacements of African and Eurasian plates (Pitman and Talwani, 1972; Burollet et *al.*, 1978; Durand-Delga and Fonbote, 1980; Boillot et *al.*, 1984).

Tunisia belonged successively to the southern paleomargin of the alpine Tethys, assembly-line of the Maghrebids and to the southern margin of the Mediterranean. Indeed, the Sahara platform, which is an immense domain limited to the North by "the down bending of the saharian", can stretch from Morocco until Tunisia. It includes massif boss with folded Paleozoic material of the African craton. This platform domain constitutes the steady fore land of the Atlasic Chains. It is affected in the oriental extremity by the south-Tunisian fault throw oriented NI20-l30. The general structure shows a well expressed reghmatic network. The major structures are oriented N-S, NW-SE and NE-SW.

They are inherited of epirogenic phases (taconic, caledonian and hercynian). In the North of the Sahara flexure the pleated fore land of the alpine chain is installed: it is the atlasic chain that includes four subfields (Fig.1):

-The southern Atlas, formed by folds oriented E - W, cut up by two major fault throw: the Gafsa fault and the fault throw of Negrine-Tozeur;

-The central Atlas containing anticlinal folds oriented N40-60 and large synclinal cut up by ditches oriented N140-150 filled up with mio-plio - quaternary deposits;

-Northern Atlas, formed by anticlinal folds bundle N40-50. The core of these folds is occupied by a lower cretaceous series. These anticlinal folds are separated by synclines filled by the tertiary sets. It is cut up longitudinally by Zaghouan important fault.

-The oriental Atlas, marked by a thick set slightly folded of Neogene according to the N-S and NE-SW directions. It corresponds to the stable domain of the Sahel.

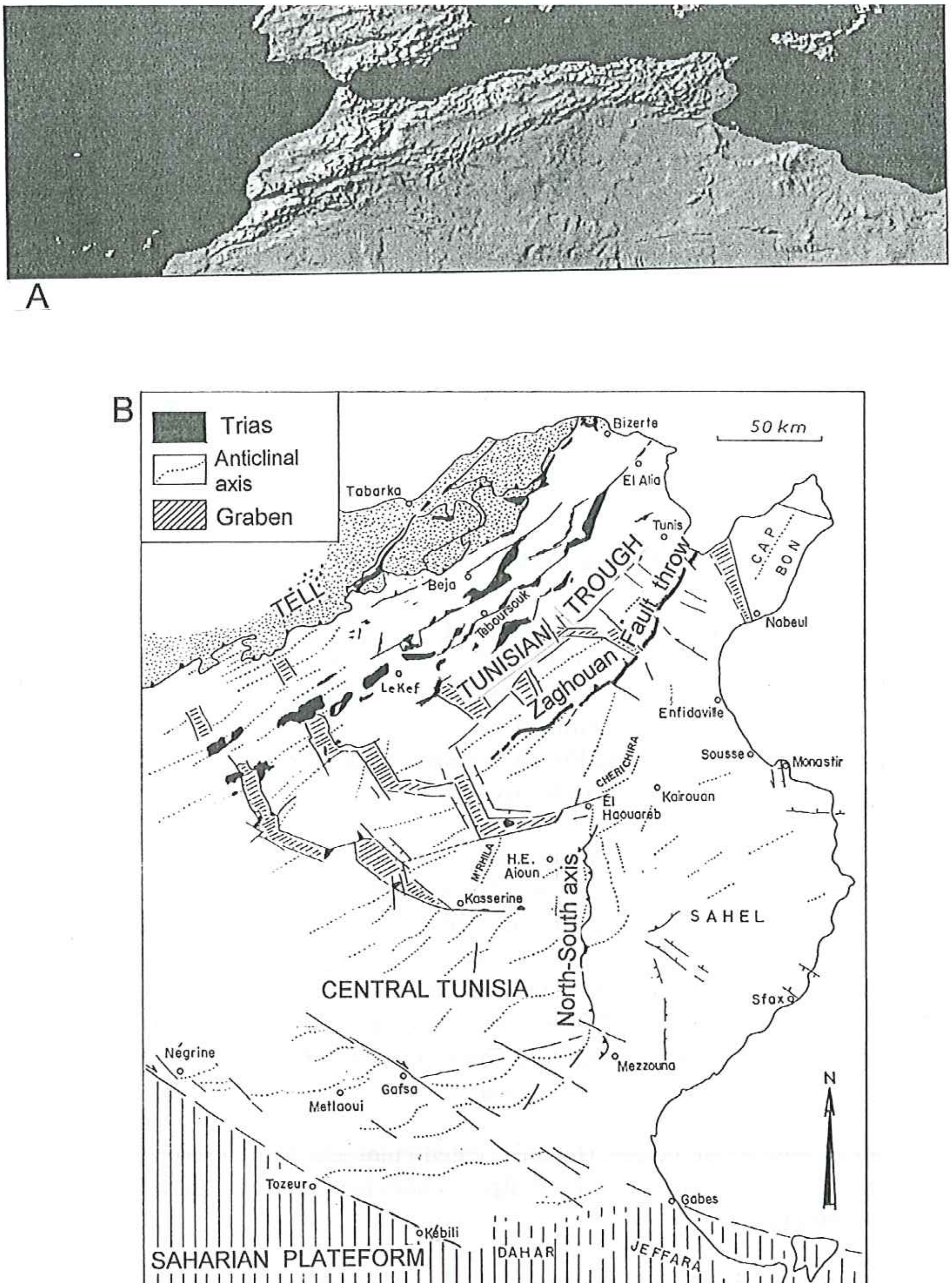

Fig. 1- General location of the Maghreb Atlas: A; Structural sketch of Tunisia (Martinez C. et Truillet R.,1987): B

The Atlasic Zone is divided into two parts, one to the East and the other to the west, by "the North-South axis" which represents a deep heterogeneous zone resulting in a surface by the meridional or submeridional flault throw.

Further to the North, the alpine chain, represented by the chain of the Maghrebids, is characterized by stackings of overthrusts; it is the zone of the Tunisian far North where allochtonous units are essentially represented by the overthrust of numidian flysch to terrigene detrital deposit superimposed to other the Tell allochtonous units.

PALEOGEOGRAPHIC EVOLUTION OF CENTRAL TUNISIA IN THE CRETACEOUS

During the Meso-Cenozoïc, central Tunisia is characterized by a shallow marine domain. It represents a transition between the Sahara craton dominated by emersions and occasionnaly submerged at the time of the major transgressions (example: Turonian) and the deep Tunisian trough (sillon tunisien) and greatly subsident.

During the Cretaceous, a lot of research activities (Pervinquière, 1903; Castany, 1951 and Burollet, 1956) put in evidence that the distribution of the sedimentary environments and the corresponding regional lithofacies, as well as the one of subsiding zones and the steady zones, are highly related to the tectonics and the paleogeography of central Tunisia (Ben Ayed, 1980; Bismuth et *al.*, 1982).

The domain of central Tunisia, borded to the South by subcontinental domain (Saharian plateform) and to the North by the opened marine domain (sillon tunisien), is very spread and is characterized by the almost-permanent presence of a continental part represented by a stable and resistant core, often emerged, corresponding to a zone of high-fund. It is that Marie et *al.* (1984) called the shoal of central Tunisia (haut-fond de Tunisie centrale).

In the lower Cretaceous, the central Tunisia platform is the opposition field between contributions of the Sahara clastic to the SW and the open marine facies to the NNW. The "North South Axis" plays a dominant role within limit the more stable platform or block pelagian.

These facies of high-fund and reductions of thickness are there frequent there: installation of reefs since the upper Jurassic and until the Berriasien ages in the northern part, uprising of the oriental compartment of "Kairouan Island" to Hauterivian-early Barremian, Aptian condensed in the Enfidha area.

The presence of tuffs, diabases and spilites, in eastern Tunisia, prominent of the volcanic activities to the Aptian that continue until the upper Cretaceous. At the end of the lower Cretaceous, movements of surrection are followed by erosion, in particular along the " North-South Axis", the upper Albian rests in unconformity on the more ancient terms in many localities (Burollet, 1956; Biely et *al.*, 1974). To the East of the " North-South Axis", frequent high zones are especially bald of cretaceous sediments (M'Rabet, 1981).

Marie et *al.* (1984) showed the existence of an important cut, of tectonic origin, separating the Aptian of the Albian and thus dividing the whole Cretaceous in two big major sedimentary cycles. To this cut corresponds a sedimentary hiatus shown by the important karstification of carbonate formations of upper Aptian. It marks the end of clastes contributions from the Sahara, resulted from the end of epirogenies throbbings affecting source regions, either to the arasement of the latter.

In the "middle Cretaceous " (Vraconian, Cenomanian, Turonian), Bismuth et *al*. (1982) put in evidence, in Tunisia Northern center, a distensive tectonic phase occurring toward the end of the Aptian leading to a partition of the northern border of the Sahara platform in distinct panels. The periodical fault reactivation of these panels in tilted blocks had a predominant role in the paleogeographic history of the central Tunisia during the middle cretaceous.

In the upper Cretaceous, in the beginning of the lower Senonian, the emerged regions are more spread. They form, ' Kasserine Island ', that is going to emerge in the Coniacian beginning and some sectors of which won't be anymore the object of marine incursions (Burollet, 1956; Marie et *al*., 1984). Only detrital continental deposits of mio-pliocenes or quaternary will accumulate there. The Campanien-Maastrichtien period is marked by a paleogeography related to a tectonic instability.

STRUCTURAL EVOLUTION OF CENTRAL TUNISIA IN THE CRETACEOUS

Structural setting:

The Central Atlas of Tunisia constitutes along with the Pelagian plateform an individualized block since Lias (Dercourt, 1985). It is separated of the Tunisian trough to the North by the fault throw NE-SW of Zaghouan and the Sahara craton to the South by the Gafsa fault.

Within this block, central Tunisia is separated from the Sahel and the oriental platform by the N-S axis corresponding to an alignment of high-fund since the lower Cretaceous (Burollet, 1956; Gourmelen, 1984; Ouali, 1984). On all sides of this alignment, there is opposition between central Tunisia more subsiding to the Secondary, but raised from the terminal Cretaceous and the more stable oriental region during the Mesozoïc, but affected by an increasing subsidence during the Cenozoïc (Ellouz, 1984).

Central Tunisia is affected by atlasic NE-SW direction. It corresponds to the present fold orientation, but also to the one of meso-cenozoïc major structures. This direction characterizes the Tunisian Atlas situated in the present extension of paleogeographic and structural Algerian atlasic domains (Soyer, 1987).

Central Tunisia constitutes thus a structural crossroads to the intersection of three major directions: N-S, NE-SW and NW -SE.

Evolution of the distortion during the Cretaceous:

According to most previous studies, the structural mesozoïc history of central Tunisia is dominated by an extension. Indeed, mesozoïc sedimentation is frequently controled by structures in normal fault and/or strike-slip fault. This distensive and/or transtensive tectonic is highly related to the expansion of tethysian domains. It affects the basement and induced a structuring of post-triassic cover by the repeated reactivation of deep flaults throw belonging to the African reghmatic network during the Jurassic and the lower Cretaceous.

In central-northern Tunisia the cretaceous sedimentary basin distribution has been controled by the three major structural directions : N-S; NE-SW and NW-SE. The deep fault throw reactivation associated to these directions and halocinetic movements of triassic évaporitic resulted in a complex tectonic. This latter was characterized by several crisis periods during the Cretaceous.

In the lower Cretaceous, many research activities mentioned an instability in the different structural domains. A distensive regime persists in the Jurassic to the lower Aptian (Khessibi, 1978,; Gourmelen, 1984; Ouali, 1984; Soyer and Tricart, 1987) and is explained by the many half-grabens of neighboring direction of E - W and by the volcanism in the Sfax-Kerkennah region (Eastern Tunisia).

The upper Aptian-Albian interval marks an instability which is going to become sharper in central Tunisia: it is " aptian crisis ". Boltenhagen (1985), Delher (1986), Soyer and Tricart (1987) assigned this " aptian tectonic phase " to an extension. The dominant feature of this extension will be the apparition of grabens of a direction close to NW-SE and the big dextral-normal fault at the same direction explaning an elongation NE-SW (Martinez et al., 1991). These authors think that if we take into account the influence of the Africa-Europe movements (transcurrent fault), this elongation corresponds to transtensive regimes having reigned in Tunisia during the lower Cretaceous (Martinez et al., 1991).

During the upper Cretaceous, from the upper Albian and until the Turonian a new extension NE-SW linked to the one that affects the Pelagian Sea and the Sahel.

It is during this epoch, that Gafsa, Kasserine and Sbiba faults (NW-SE) occur and seem to be at the origin of the platform beaking up in distinct panels. The fault reactivations gave birth to the tilted blocks. In the Senonian, we notice a flexuration of the cover in the North-south axis associated with the sinking of Eastern Tunisia and the uprising of atlasic Tunisia. In the Campanian-Maastrichtian, the extension persists in central Tunisia. During this period, the tectono-sedimentary evolution of the northern sector of the Kasserine region, for example, show that this area of central Tunisia seems to be affected by a distensive to transtensive distortion oriented NNE-SSW to N-S (Dlala, 2001).

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MAIN UNCONFORMITIES AND ASSOCIATED EARLY DIAGENETIC FEARURES IN CENTRAL TUNISIA (SOUTHERN TETHYAN MARGIN) DURING THE LATE APTIAN - TURONIAN INTERVAL

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I-INTRODUCTION

Following the terrigenous clastic-dominated depositional megacycle having marked in particular southern and central Tunisia area (Fig.1) during Early Cretaceous times (M'Rabet, 1987), many carbonate platforms (*sensu lato*) have taken place within this area starting from the Aptian and during the whole Late Cretaceous interval (Fig.2). These platforms are usually separated by argillaceous deposit units defining transgressive/regressive cycles such as the carbonate platforms occurred during the regressive phases.

The carbonate platforms are commonly capped by emergent surfaces which are more or less truncated due to sub-aerial erosion, representing therefore major unconformities and materializing sequence boundaries. Particularly, the Late Aptian-Turonian deposits includes apparently three major unconformities which can be widely followed along both southern and central Tunisia and considered as third order sequence boundaries limiting four depositional sequences. From bottom to top, these unconformities are represented by the emergent surfaces of the following carbonate platforms (i) Orbata/Serj or its equivalents (Late Aptian) (ii) intra-Biréno (Middle Turonian) and (iii) Douleb (Late Turonian to probable Coniacian). According to the global eustatic chart (Haq et al., 1988; Hardenbol et al., 1998) these surfaces are correlatable respectively with SB 107.5, SB 91 and SB 90 and can be plausibly related to sea level falls. Nevertheless, local tectonic activities have also more or less marked these unconformities.

These distinctive platform surfaces have been earlier affected by various sub-aerial vadose diagenetic processes the prominent of which are dissolution (karstification) and dolomitization. Dolomites occurred preferentially in the uppermost carbonate platform levels below unconformities as well as closely within the exposed surfaces what suggest that such diagenetic features are related to contemporaneous relative sea level falls which can be both eustatic and tectonic derived. Within the same unconformity surface sometimes occur indices of successive emersions to which are superimposed in addition those of the alternating transgressive intervals. Considering differences in environment conditions (*i.e.* composition of exposed surfaces, diagenetic processes amplitude), the preserved diagenetic features do not always reflect period of sub-aerial exposure and amplitude of associated weathering (*i.e.* both Middle and Late Turonian platform surfaces). Moreover, the different sub-aerially weathered surfaces are not equally susceptible to be dismantled and eroded. However, within the series the biostratigraphy of which is already established (*i.e.* Late Aptian platform Surface) times of sub-aerial exposure and associated weathering can be assessed.

In the present paper we intend to examine in the Late Aptian – Turonian interval only the major unconformity surfaces which correspond to sequence boundaries and where early diagenetic features are sufficiently preserved to be studied.

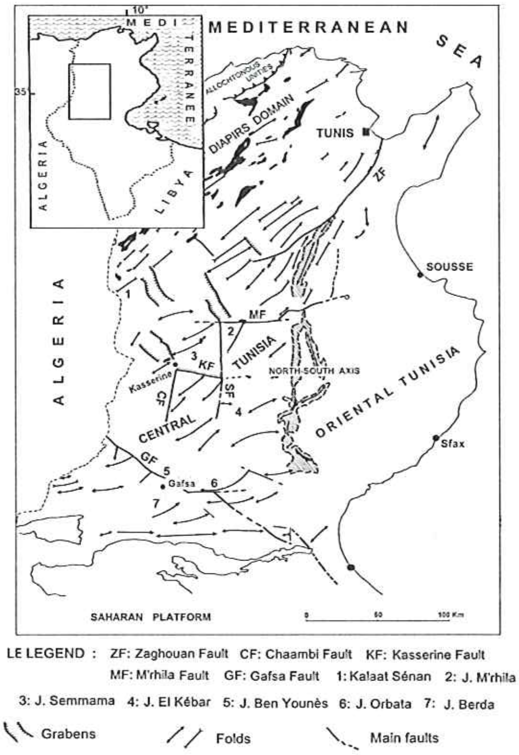


Fig. 1. Location map of Central Tunisia showing the structural units and outcropping Aptian-Turonian areas.

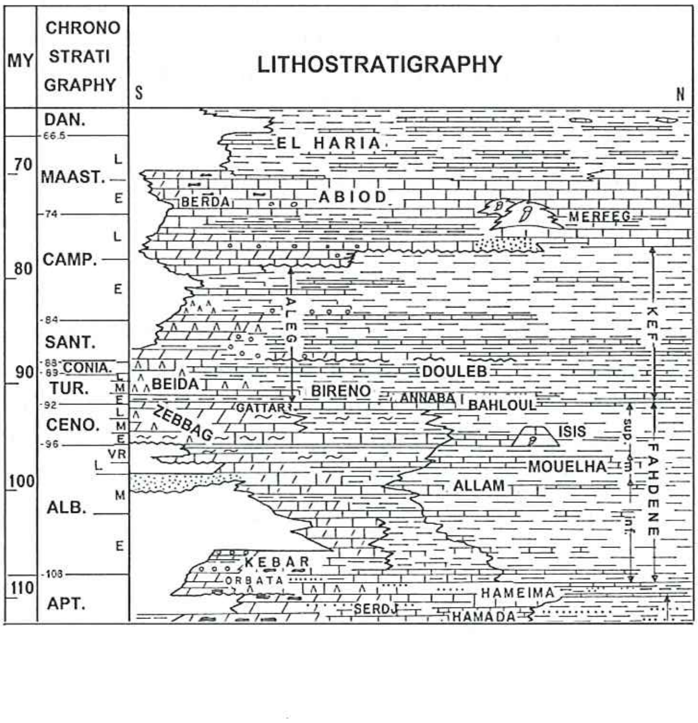
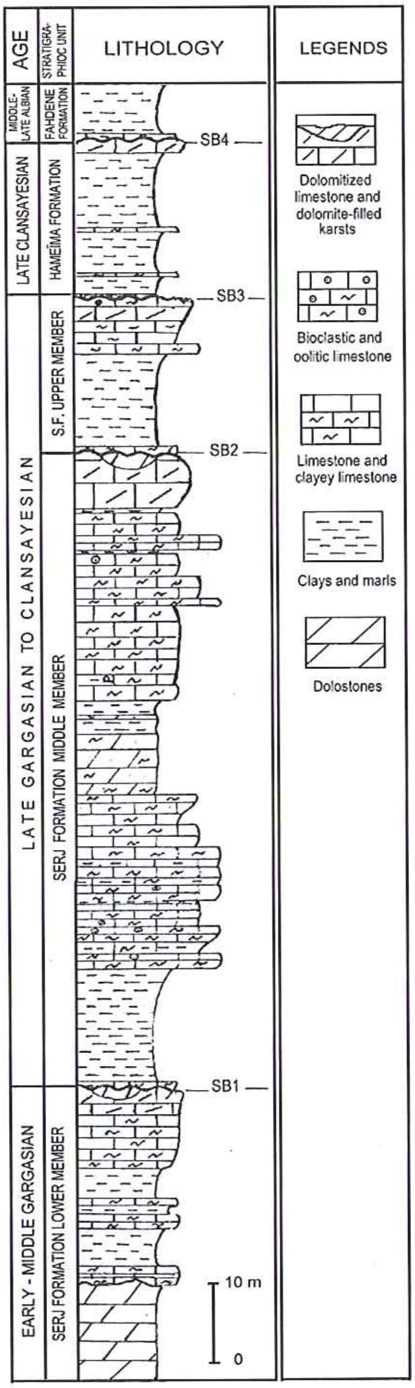


Fig.2 - Stratigraphic sketch of the Tunisian Late Cretaceous, in M'Rabet et al.(1995).

II-THE LATE APTIAN CARBONATE PLATFORM SURFACE (SB D4)



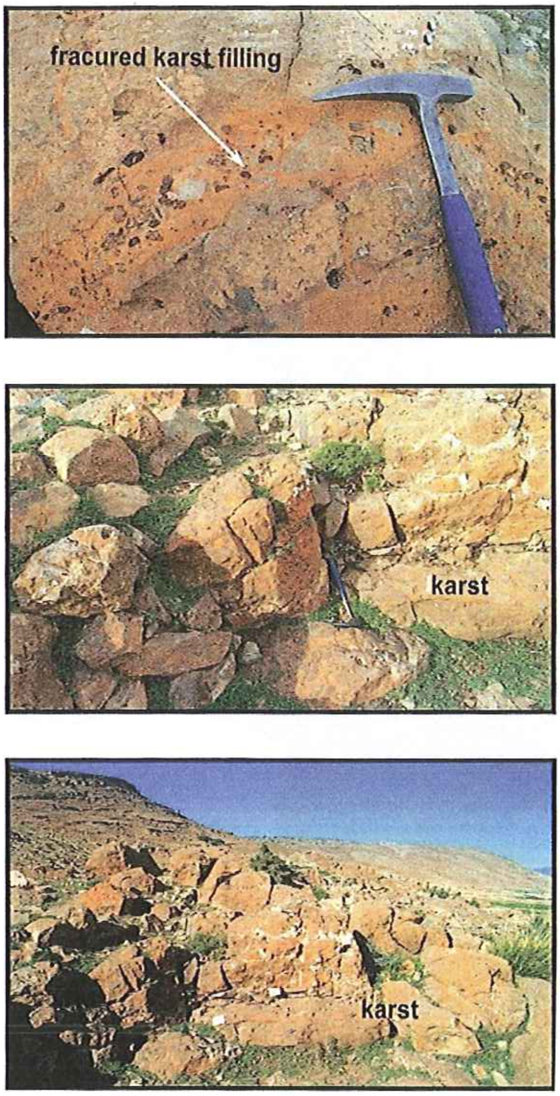


Fig. 3 - Main Aptian unconformities and karsts marking (SB D4), Jebel El Hamra, western-central Tunisia (Echihaoui, 2004, modified).

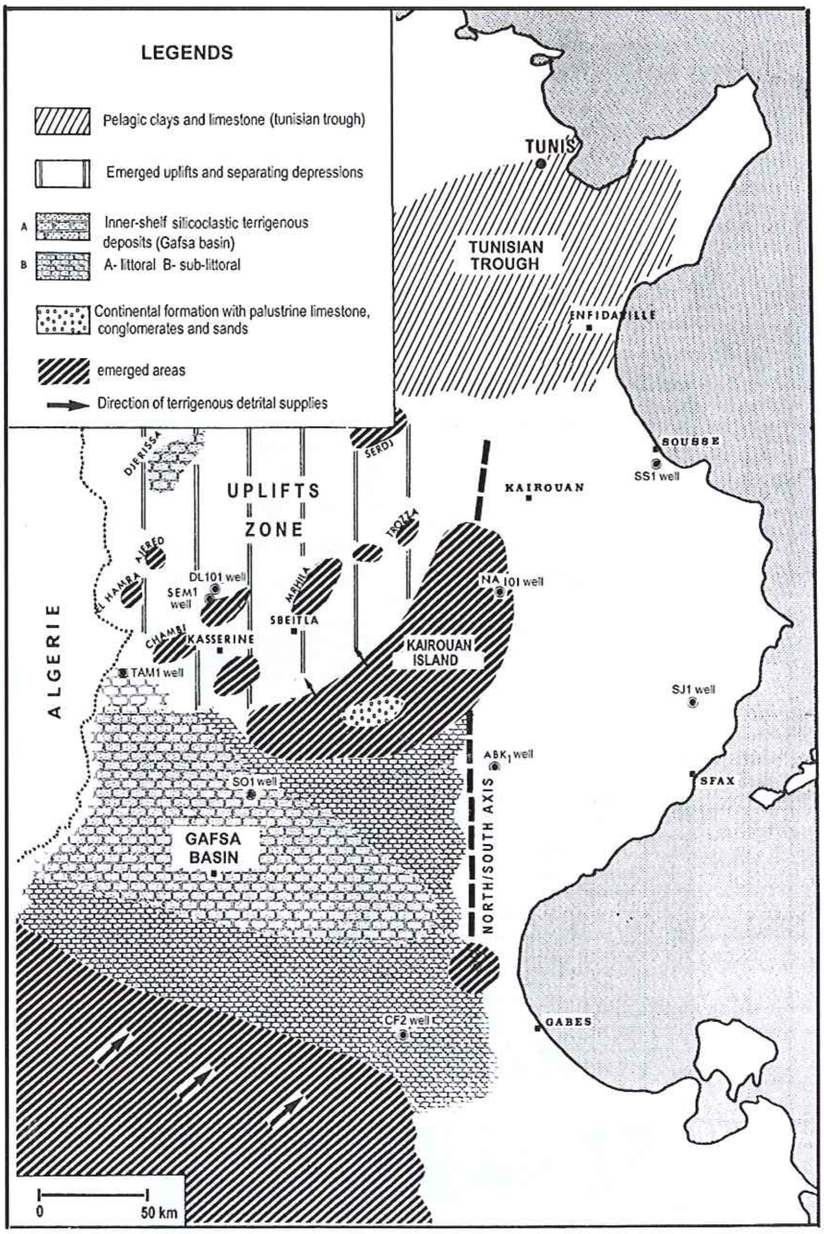


Fig. 4 - Paleogeographical sketch map of central Tunisia during the Late Gargasian to Clansayesian interval showing both the inner-shelf and outer-shelf settings of the Late Aptian platforms (in M'Rabet, 1987, modified).

In particular, the youngest Late Aptian (Late Clansayesian) carbonate platform surface is directly overlain by Middle Albian *p.p.* deposits (Fig.5, ph.A), materializing a major unconformity generalized in central Tunisia area and also extends both toward southern (M'rabet, 1987; Ben Youssef, 1999) and northern Tunisia. Locally (i.e. Jebel Hamra, western central Tunisia) this surface records apparently three sub-aerial exposures during the Early Albian-Middle Albian *p.p.* interval. Indeed, the prominent karsts of metric size observed within the uppermost Aptian carbonate bar are associated to three distinctive filling-up stages which are sometimes separated by truncated erosional surfaces what suggests three successive emersion/transgression cycles. The different karst-filling generations having marked the alternating transgressive intervals are composed mainly with orbitolite-rich limy sediment associated to phosphates and glauconite (Fig.5).

The quite prominent karstification phenomenon having marked the uppermost Late Aptian unconformity (Fig.3) is a result of the CO_2-rich meteoric waters having conquered the platform during the sea level fall (SB D4) and then led to sub-aerial exposure. Such deep karstification reflects the relatively long period of sub-aerial exposure of the platform and associated deep weathering as well. In addition to meteoric water-related dissolution, early dolomitization has affected the uppermost levels of the Late Clansayesian platform as well as the karst fillings. These features are also locally associated to many pedogenetic indices (i.e. microcodium). Considering the biostratigraphical data, the stratigraphic gap corresponding to the considered Late Aptian unconformity has lasted successively the Late Clansayesian p.p., the Early Albian and the lower part of the Middle Albian (Echihaoui, 2004).

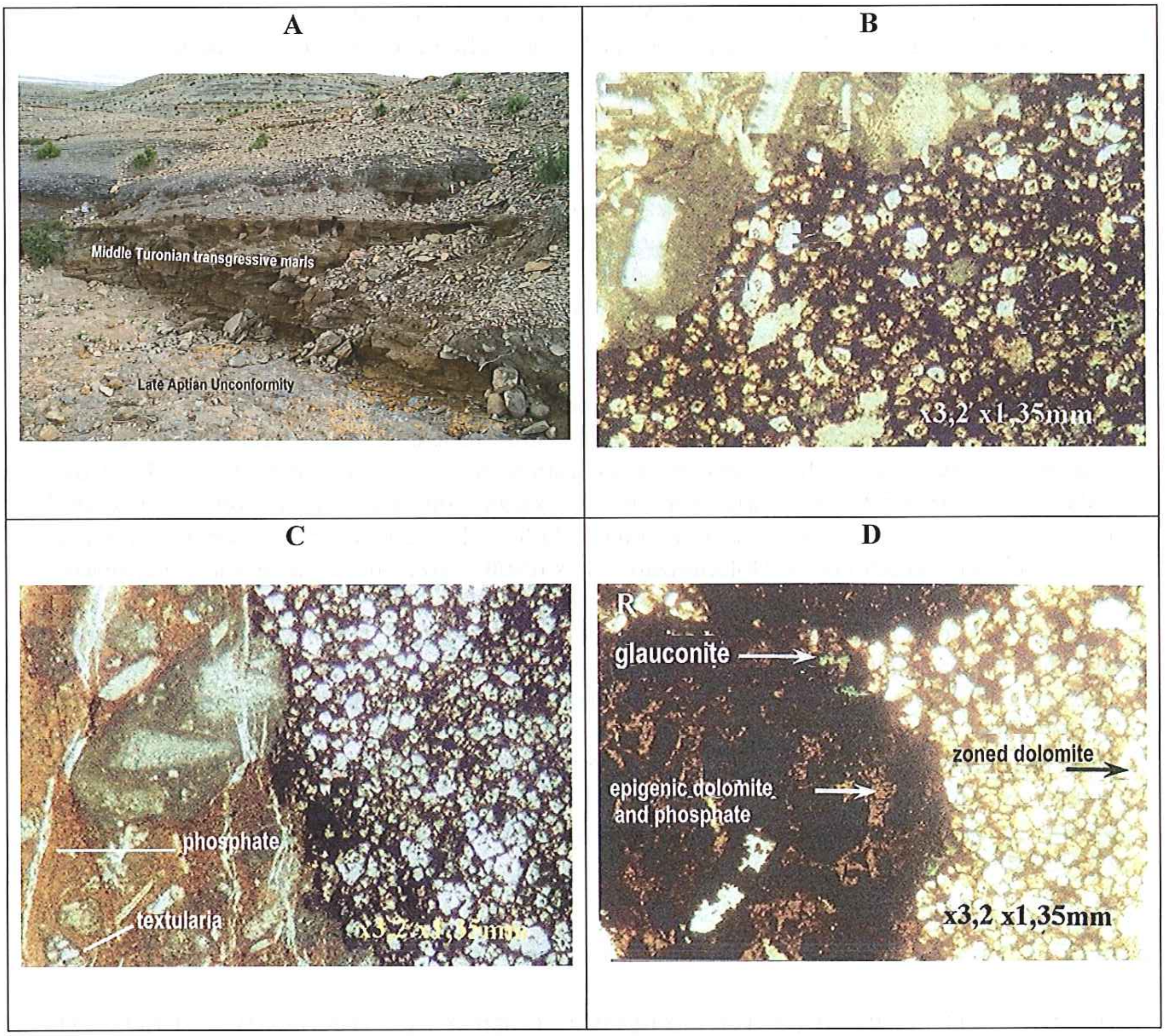


Fig. 5 -.Different karst-filling generations within the Late Aptian carbonate platform surface (Late Clanseysian unconformity). A- First filling generation: Orbitolite-rich limlestone and clays (upper-left part) against the platform dolostone (lower-right part). B- Second filling generation: bioclastic limestone epigenized into phosphates (left part) against the platform dolostone (right part). C- Third filling generation: dolomitized and phosphatized carbonate material.

While going eastward in central Tunisia (Kasserine region), where the north-eastern platform margin seems to have been existed during the Late Aptian (i.e. Jebel Semmama and Jebel M'rhila sectors) the sedimentary hiatus related to the last Late Aptian platform sub-aerial exposure is rather longer compared to that described in the western central Tunisian since in the first area the Late Aptian platform is directly overlain by Vraconian marls. Nevertheless, karstification phenomenon is not as developed as in the western central Tunisia, all the more as the total thickness of the preserved sub-aerially weathered carbonate levels is less important too. This suggests that the platform has been longer exposed in eastern central Tunisia than in the western area what has apparently led to deeper weathering of the platform surface and more susceptibility to dismantlement as well as erosion.

Locally in central Tunisia (i.e. Jebel Kébar sector) a continental formation made of lacustrine and fluvial deposits intercalated with pedogenetic horizons (paleosols) occurred. This formation which covers the Early Albian to Middle Albian p.p. interval (Khessibi, 1978) has absorbed the three latest Aptian unconformities observed elsewhere in central Tunisia area.

The sub-aerial diagenetic processes having affected the different Late Aptian platform surfaces and in particular the youngest one (Late Clansayesian) consists notably of dissolution, cementation and dolomitization. Dissolution is illustrated by many apparent features such as karsts (epi-karsts, open karsts, Fig.3), leached bioclasts, mud-crack enlargement as well as many dissolution micro-channels crossing the micritic matrix; furthermore, some dissolution voids are filled-up with internal sediments (geopetal vadose silt) what indicates clearly earliness of dissolution.

Early cementation consists either of stalactitic or drusic sparry calcite cement. Such cements can be resulted from temporary saturation of waters with respect to $CaCO3$ due either to superficial or nearly superficial evaporation process. Dolomites occurred preferentially toward the uppermost carbonate platform levels below the exposure surface as well as closely within karsts. Dolomitization has resulted from mixed meteoric water/marine water due to the Late Aptian sea level fall (SB 107.5 MA) which should have led subsequently to introduction and circulation of meteoric waters within marine ground-waters and then dolomitization of the platform; marine waters were largely dominated by meteoric ones as testify both negative isotopic ratios and impoverishment in Sr with respectively $\delta^{18}O = -10.5$ PDB and Sr = 30 ppm, in average. Furthermore, to such indices is added a gradual impoverishment in Fe^{++} toward the unconformity surface depending on the O2-rich meteoric waters by which Fe^{++} should have been oxidized into Fe^{+++}. Although such features are clearly indicating meteoric water influences, dolomitization by the Dorag model (Badiozamani, 1973) remains also possible.

III-THE LATE TURONIAN TO PROBABLE CONIACIAN (DOULEB) CARBONATE PLATFORM SURFACE (SB 90 MA)

The Douleb Member defines in central Tunisia a 70 to 100 metres thick carbonate platform (Fig.6) which is Late Turonian to probable Coniacian in age (Bismuth et al., 1981; Touir et al., 1989). It is bounded at the top by a sub-aerial erosion surface abruptly overlain by the so-called Aleg Formation transgressive conglomerates and then by marls and limestone intercalations (Fig.7, ph. A,B,C,D). This surface materializes a widely extended major unconformity which is correlatable not only all over both central and southern Tunisia but also with the global sequence boundary SB 90 MA (Haq et al., 1988; Hardenbol et al., 1998).

The Douleb platform surface shows various early diagenetic features related to the Late Turonian sea level fall having led to the platform exposure (Touir & Zaghbib-Turki, 2004). The uppermost carbonate beds are slightly dolomitized but dissolution and cementation are the most impressive processes and they are usually associated to internal sediments indicating undoubtedly earliness of dissolution. Indeed, dissolution is mostly illustrated by many moldic vugs in which have deposited various internal sediments (Fig.7, ph. E,F). The latter are well documented in Troudi (1998) and Touir (1999) whose have distinguished three main kinds of internal sediments which can be sometimes superimposed within the same dissolution void.

III-1- Well sorted fine-grained geopetal vadose silts

These internal sediments are usually overlying a thin cement horizon that outlines the dissolution vugs, whereas the remaining void space is later obliterated by sparry calcite cement.

III -2- Coarse-grained sediments with poorly-sorted pellets and bioclasts

The coarse-grained bioclasts and pellets forming such internal sediments should have been dismantled from the void vault and then deposited on the floor.

III -3- Centrifuge micritic sediments

These internal sediments are outlining both walls and vault of dissolution voids and can be in addition deposited on the floor; moreover, the micritic material is sometimes crossed by dissolution-related micro-channels. Such centrifuge sediments should have been occurred due to percolation of unsaturated muddy waters. According to M'Rabet (1987), it is to be rejected that such micrite can be in part resulted from chemical precipitation notably when skeletal debris are lacking in the internal sediments.

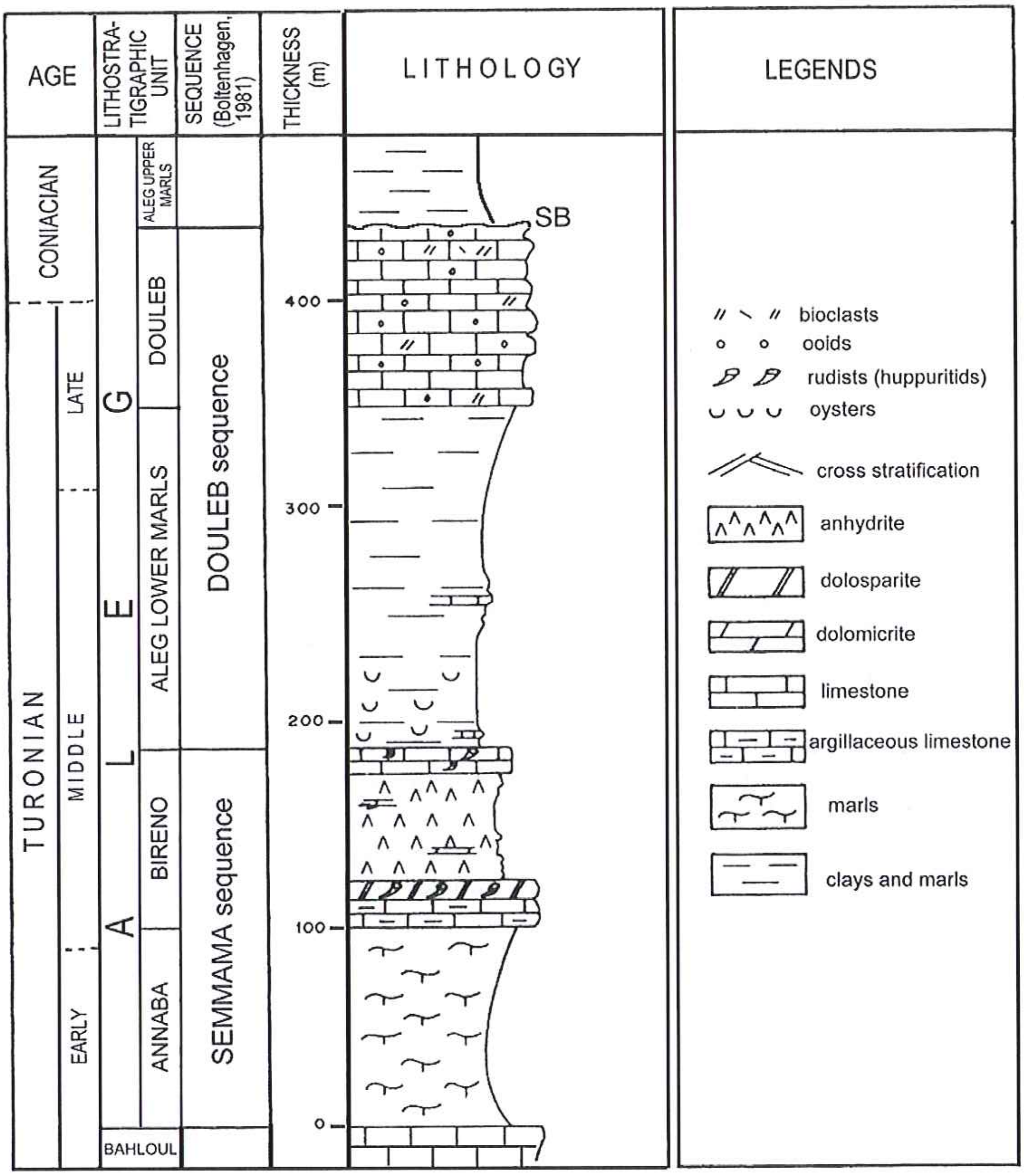


Fig. 6 - General litho-stratigraphy of the Turonian deposits outcropping in central Tunisia (i.e. Kasserine area) showing the Late Turonian to probable Coniacian unconformity (in Bismuth et al., 1981, modified).

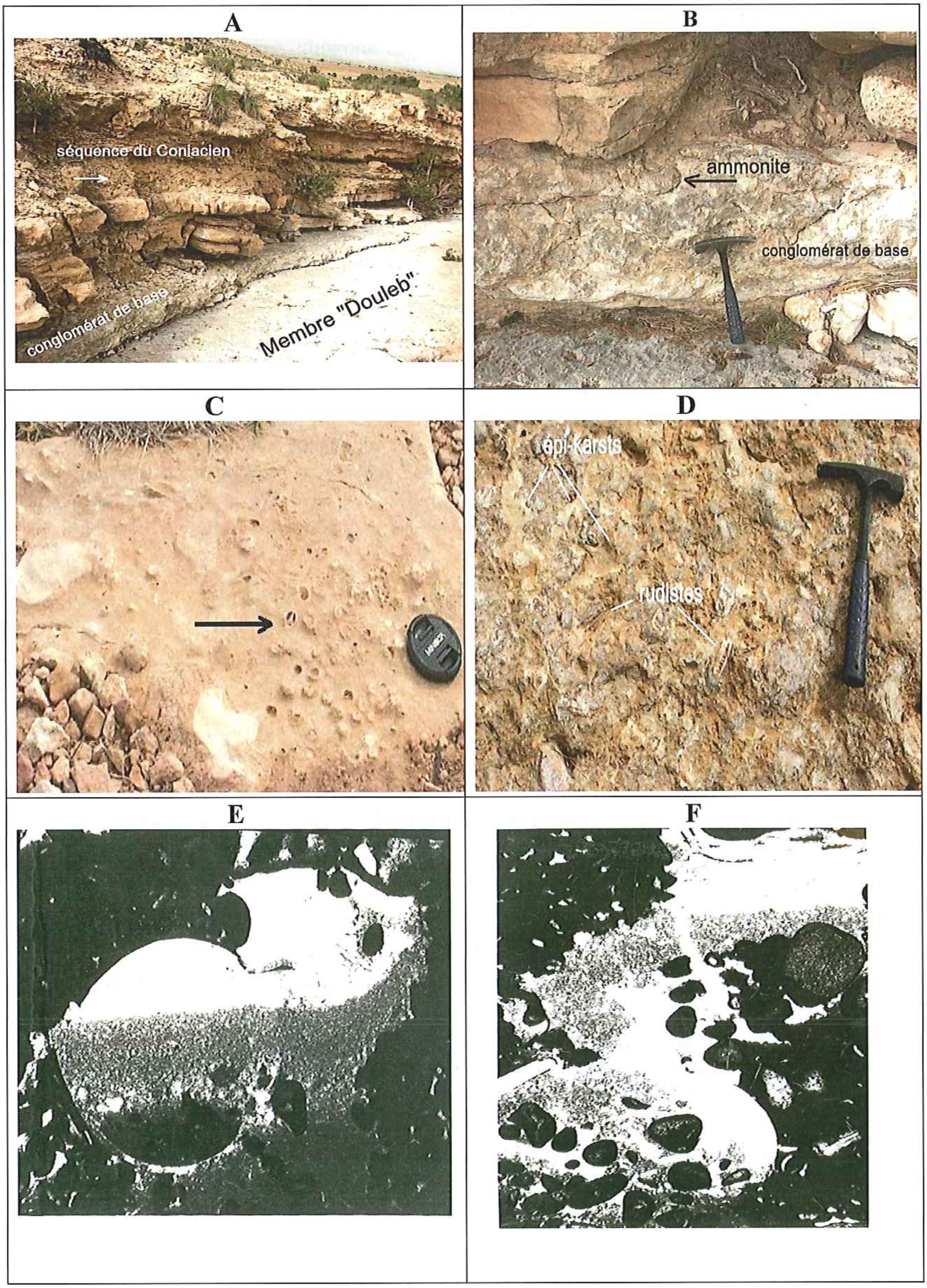


Fig. 7 - The Late Turonian to probable Coniacian unconformity in Jebel M'rhila, central Tunisia (in Touir & Zaghbib-Turki, 2004). A- Coniacian transgressive conglomerates and

alternating marls and limestones overlying the Douleb carbonate platform upper surface. B- Zoom on the previous transgressive conglomerates showing ammonites. C- The Douleb platform surface uppershowing locally rudist communities in growth position with dissolved shells. D- Zoom on the Douleb platform upper surface with scattered epikarsts and dissolved rudist shells. E- A dissolved gastropod shell partially filled with geopetal micritic internal sediment; micrite is overlying micro-sparry calcite early cement and the remaining dissolution void has been obliterated by late sparry calcite cement.F- A dissolution vug containing both centrifuge micritic and coarse-grained (pellet) internal sediments.

V- CONCLUSIONS

Three main unconformities are marking the Late Aptian to Late Turonian deposit column in central Tunisia, namely the Late Aptian (Late Clansyesian), Middle Turonian and Late Turonian to probable Coniacian unconformities. They are represented by carbonate platform sub-aerial exposure surfaces which are related mainly to eustatic sea level falls since they materialize sequence boundaries correlatable with third order global eustatic cycles.

These distinctive surfaces show various early diagenetic features (*i.e.* karstification, dolomitization) related to sea level lowering that has led to meteoric water introduction through carbonate platforms. In particular, within the Late Clansayesian platform surface are superimposed features of at least three successive exposures separated by transgressive intervals.

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LATE CRETACEOUS DEPOSITS IN CENTRAL TUNISIA (TETHYAN SOUTHERN MARGIN): STRATIGRAPHY, PALEOGEOGRAPHY AND MAIN DEPOSITIONAL CYCLES

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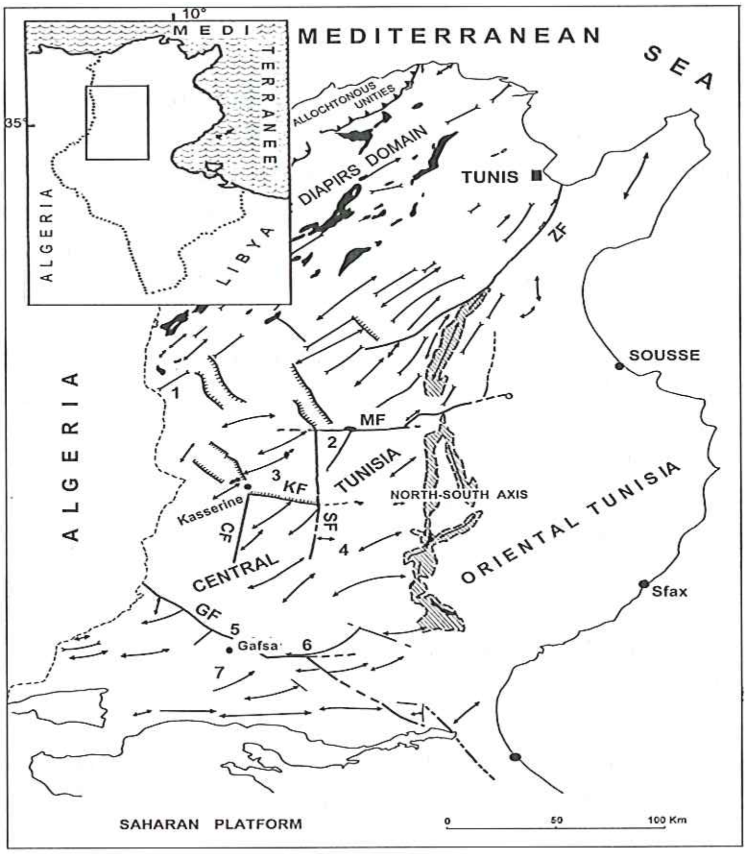
I- INTRODUCTION

The Cretaceous series in Tunisia include two depositional megacycles usually separated by a largely recognized major Aptian-Albian unconformity due to the Early to Middle Albian hiatus; it can be observed notably along central and southern Tunisia whereas toward the north sedimentation was rather incessant during this period. In this paper we intend to discuss only Late Cretaceous deposits overlaying this unconformity in central Tunisia area where the main features of local and global changes can be observed. During the Late Cretaceous at the southern Tethyan margin, Tunisia area included a wide continental platform displaying a basinward stepped structure composed of two main tilting blocks bounded by the major NW-SE to E-W trended faults (*i.e.* Gafsa fault, Kasserine fault, M'rhila fault). The northern block corresponds to an outer-shelf which passes gradually northward into an open marine basin (*Tunisia trench*) whereas the southern one describes an inner-shelf which grades southward into a littoral to continental domain (*Saharan platform*). On the other hand, the central Tunisia platform was – since at least the Jurassic – limited to the east by a N-S trended large high zone so-called N/S axis (Bonnefous, 1972; Soussi, 2000; Bouaziz *et al.*, 2002). Such a structure has worked during the Cretaceous as a paleogeographic barrier separating the central Tunisia platform from the oriental Tunisia open sea. While going from this barrier toward the western central Tunisia, the platform also displays a westward stepped series of blocks limited by N-S oriented major faults (*i.e.* Sidi Ali Ben Aoun fault, Châambi fault). It is in such structural and paleogeographical frameworks that the Late Cretaceous deposits have taken place.

The Late Cretaceous depositional series -particularly those outcropping in central Tunisia- have been explored as early as the beginning of the last century. First, works were devoted to paleontology and stratigraphy as well as geological structures. Although Pervinquière (1903) is the first contributor to have carried out a fairly exhaustive paleontological inventory and sketched stratigraphy of the Tunisian Cretaceous outcrops, Burollet (1956) has the merit to have established the first detailed stratigraphic chart of these series while subdividing them into regionally correlative litho-stratigraphic units (*Formations*). A revision of the Late Cretaceous units has been later carried out by Fournié (1978) and a recent synthesis of Tunisia Cretaceous stratigraphy can be found in Ben Ferjani *et al.* (1990) and M'Rabet *et al.* (1995). The latter have in particular reviewed and also catalogued the Cretaceous type sections. The first attempts to the study of Late Cretaceous paleogeography of Tunisia are due to Boltenhagen (1981) who especially sketched the Middle Cretaceous paleogeography of central Tunisia and then a general view on Late Cretaceous paleogeography of the whole Tunisia was carried out by Marie *et al.* (1984).



LEGEND : ZF: Zaghouan Fault CF: Chaambi Fault KF: Kasserine Fault MF: M'rhila Fault GF: Gafsa Fault 1: Kalaat Sénan 2: J. M'rhila 3: J. Semmama 4: J. El Kébar 5: J. Ben Younès 6: J. Orbata 7: J. Berda

Grabens Folds Main faults

Fig.1 - . Location map of Central Tunisia showing the structural units and outcropping Aptian-Turonian

Contributions on stratigraphy of the Late Cretaceous records in central Tunisia have succeeded the last years, while becoming more and more focused on definite stratigraphic intervals such as Vraconian-Turonian (Boltenhagen, 1981; Bismuth *et al.*, 1981), Cenomanian-Turonian (Saïdi, 1996; Troudi, 1998; Matmati, 1999; Touir, 1999; Touir & Soussi, 2003) and Senonian (Negra, 1994; Zaghbib-Turki & Turki, 2001). A relatively exhaustive biostratoigraphic inventory aiming at the whole Late cretaceous deposits in central Tunisia was notably carried out by Touir *et al.* (1989); many other contributions have been also devoted to biostratigraphy but focusing definite stages, such as the Albian (Zghal *et al.*, 1994, 1996; Memmi, 1999; Echihaoui, 2004), Vraconian-Turonian (Bismuth *et al.*, 1981), Cenomanian (Gargouri-Razgallah, 1983; Robaszynski *et al.*, 1994), Cenomanian-Turonian boundary (Razgallah *et al.*, 1994; Abdallah & Meister, 1997) and Senonian (Negra, 1994; Abdallah, 1987; Touir & Zaghbib-Turki, 2004). As for sequence stacking of Cretaceous deposits, except the sequence analysis carried out by M'Rabet (1981, 1987) exclusively on Early Cretaceous records, the first attempt to establish a Late Cretaceous sequence pattern is due to Boltenhagen (1981) which has subdivided the Middle Cretaceous deposits into four transgressive/regressive sequences, on the basis of vertical litho-facies variation. Currently, works are rather oriented to sequence stratigraphy analysis (Robaszynski *et al.*, 1990; Saïdi, 1996; Troudi, 1998; Matmati, 1999; Touir, 1999; Touir & Soussi, 2003; Ben Youssef, 1999). The Cretaceous series in central Tunisia have been also subject of subsurface exploration undertaken by petroleum companies, the results of which still remain non published, except some ones (Brahim, 1983; Ben Ferjani *et al.*, 1990; Bédir *et al.*, 1996).

In the hope to simplify the Tunisian Late Cretaceous stratigraphy to readers wile providing them in addition a new overview on evolution of the different lithostratigraphic units this paper aims at following objectives:

- Providing a synthetic overview on the Late Cretaceous stratigraphic units (*Formations*) covering the central Tunisia area in terms of depositional cycles (Fig. 2).
- Discussing the contemporaneous structural and paleogeographical frameworks in which these *Formations* have occurred, knowing that central Tunisia platform includes commonly an outer-shelf to basin transition zone in the north (Kasserine region), a high zone in the centre (Sidi Bouzid region) and an inner-shelf with evaporitic annexes in the south (Gafsa region) (Fig. 3).
- Subdividing the Late Creataceous lithostratigraphic column into depositional cycles bounded by locally and globally correlatable unconformities (Fig. 4), on the basis of regional correlations of the major sedimentary breaks while referring in addition to the global eustatic chart (Haq *et al.*, 1988; Hardenbol *et al.*, 1998).

It is to be noted that the geographical distribution of facies and inferred sedimentary environments as well as paleogeographical and structural frameworks are all considered in this paper according to an overall N-S transect.

II- OVERVIEW ON THE MAIN LATE CRETACEOUS LITHO-STRATIGRAPHIC UNITS (*FORMATIONS*) IN CENTRAL TUNISIA

There is a prominent litho-facies variation from northern (basin domain) to southern (platform domain) Tunisia (Fig. 2), hence litostratigraphic units were called differently. From bottom to top we distinguish successively:

- *Serdj/Orbata Formation,* Burollet (1956), widespread carbonate platform mainly Gargasian (*Orbata*) in central and southern Tunisia (M'Rabet, 1981-1987) and Latest Aptian to probable Albian (*Serdj*) towards the north (Tlatli, 1980).
- *Kébar Formation* (Khessibi, 1978), Late Aptian- Early to Middle Albian, continental (fluviatile and pedogenetic) unit overlying locally the truncated Aptian *Orbata* platform.
- *Fahdène/Zebbag Formation* (Burollet, 1956), Early to Middle Albian-Late Cenomanian, marls unit (*Fahdène Formation*) in the north (basin) becoming rich in carbonate intercalations in the northern central Tunisia (outer shelf and platform/basin transitional zone), relayed by carbonates and evaporates forming the *Zebbag Formatio*n toward the south (inner-shelf); this is subdivided by Fournié (1978) into five distinct lithologic *Members* including at the top the *Gattar carbonate Member*.
- *Bahloul Formation* (Burollet, 1956), Late Cenomanian to low Early Turonian in northern Tunisia and only Late Cenomanian in central Tunisia, foliated fine-grained pelagic limestone, showing euxinic facies both in norhern Tunisia (basin) and locally in the south (Gafsa trough).
- *Kef/Aleg Formation*, Early Turonian-Early Campanian, showing in northern Tunisia (basin) a nearly 2500 m thick mass of marls with very thin carbonate intercalations (*Kef Formation*), subdivided into ten distinct terms- term a to term j- (Fournié, 1978), while passing towards the centre and the south (platform) into the *Aleg Formation* (Burollet, 1956) that shows various litho-facies including the following different Members:

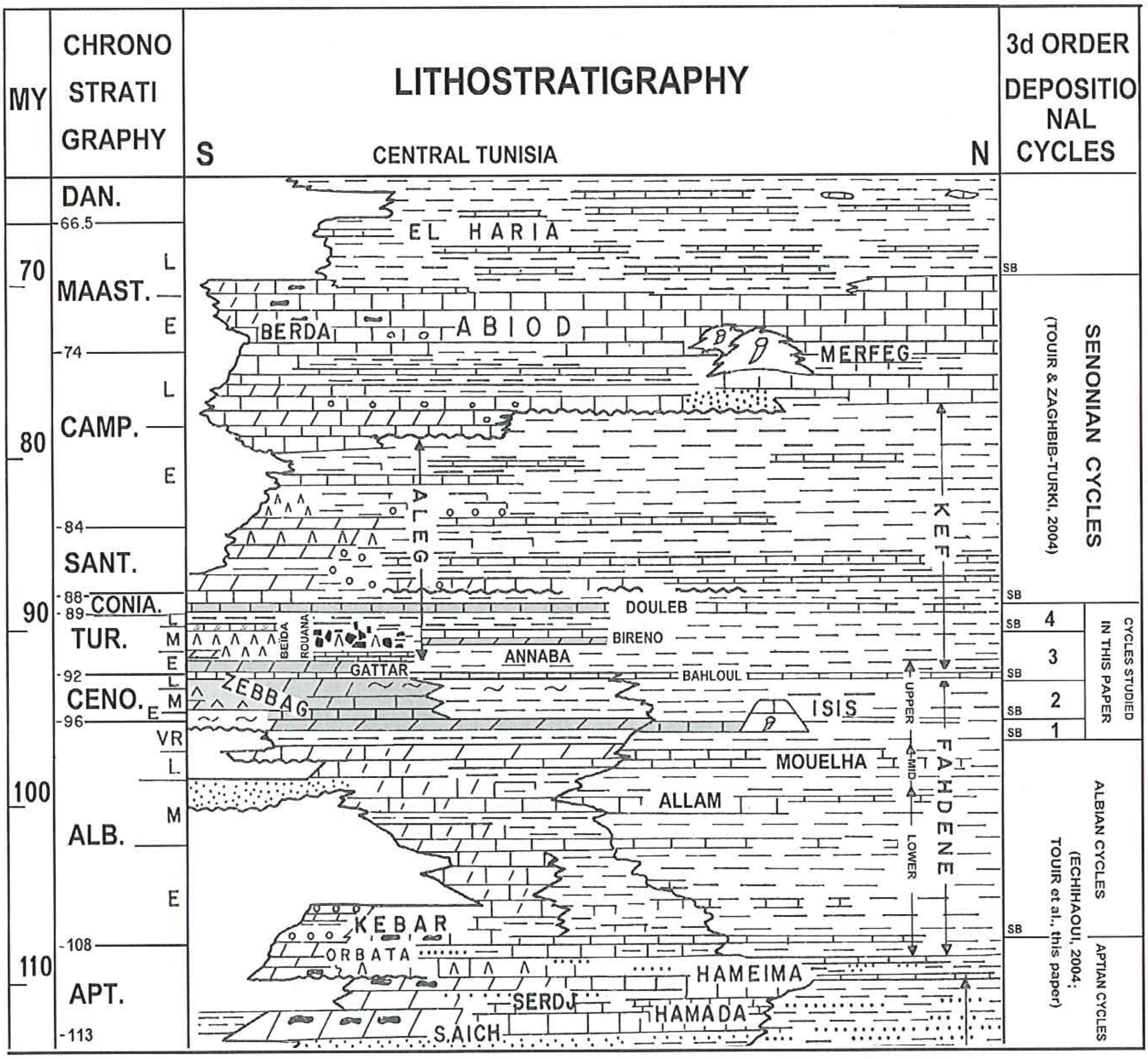


Fig. 2 - Tunisian Late Cretaceous stratigraphic sketch (in M'Rabet et al., 1995, modified).

- ✓ *Annaba Member* (Burollet, 1956), Early Turonian, occurs mainly in the northern central Tunisia (Kasserine region) and locally in the south (Gafsa region), subdivided into two distinct terms with ammonite-rich marls in the lower term and alternating marls and limestones rich in benthic fauna in the upper one (Touir & Soussi, 2003).
- ✓ *Biréno Member* (Burollet, 1956), Middle Turonian, composed of two main carbonate terms: a rudist-bearing dolomitic lower term -locally relayed by stromatolithes and desiccation breccias- and a limestone upper term; characterizing the northern central Tunisia.
- ✓ *Beïda Member* (Boltenhagen & Mahjoub, 1974; *in* Fournier, 1978), Early to Middle Turonian, likely equivalent of the whole *Annaba* and *Biréno* (lower term) *Members*, 100 m-thick anhydrite unit intercalated by thin laminated dolomitic levels, occurring locally to the north of the Gafsa fault as well as farther southward.

- ✓ *Boudouaou Member*, (Fournié, 1978), Early to Middle Turonian, rudist-rich limestone succession with rare marl intercalations, occurring locally to the north of the Gafsa fault as an equivalent of the anhydritic *Beïda Member*, also equivalent of the whole *Annaba* and *Biréno Members*.
- ✓ *"Marnes inférieures de l'Aleg" Member* (Bismuth *et al.*, 1981), Middle to Late Turonian, marls unit with centimetric limestone and lumachelle intercalations, covering the whole central Tunisia.
- ✓ *Douleb Member* (Burollet, 1956), Late Turonian to Coniacian, carbonate bar covering overall the central Tunisia including the N/S axis high zone and extending toward southern Tunisia.
- ✓ *Rouana Member* (Khessibi, 1978), Turonian, equivalent of the following *Members* succession: *Annaba*, *Biréno* and *"marnes inférieures de l'Aleg"* (Châabane, 2005), polygenic breccia unit associated to anhydritic matrix and carbonate intercalations, restricted to the middle part of central Tunisia (Sidi Bouzid region).
- ✓ *"Marnes supérieures de l'Aleg" Member* (Bismuth *et al.*, 1981; Touir & Zaghbib-Turki, 2004), Coniacian-Late Campanian, silty marls with thin dolomitic and bioclastic limestone intercalations, overlain by the chalky-like limestone succession forming the so-called *Abiod Formation* (Late Campanian to Maastrichtian) by which ends the Late Cretaceous megacycle in Tunisia. The last two units exceed of course the present paper.

III-ALBIAN-LATE CENOMANIAN P.P. DEPOSITS: *FAHDENE/ZEBBAG FORMATION*

In northern central Tunisia (platform/basin transition) and farther to north (basin) the Albian – Late Cenomanian interval corresponds to the marly *Fahdène Formation* which is subdivided into three *shale Members* the uppermost of which includes two distinctive lower (Vraconian) and upper (Cenomanian) terms; whereas toward the south (platform) it corresponds to the carbonate and evaporate *Zebbag Formation* (Fig. 4).

The Early to Late Albian hiatus having marked the most part of the central and southern Tunisia (platform domain) is largely recognized throughout Tunisian fields (Burollet, 1956; Bismuth, 1973; Khessibi, 1978; Ben Youssef, 1980; M'Rabet, 1981- 1987; Bismuth *et al.*, 1981; Touir, 1999) and regarded to be mainly related to eustatic sea level fall. Nevertheless, it should have been also more or less influenced by local Late Aptian tectonic activities (Austrian phase) that are widely described and documented in central Tunisia (Chihi *et al.*, 1984; Ben Ayed, 1993; El Euchi, 1993; Bouaziz *et al.*, 2002); contemporaneous halokinetic movements should have also intervened with tectonics (Ben Brahim, 1983; Boukadi & Bédir, 1996). The resulting sea level fall has led to emersion of the Late Aptian carbonate platform (*Serdj/Orbata platform*) and so to weathering and erosion processes. Simultaneously, a continental formation including fluviatile and pedogenetic sediments (*Kébar Formation*) occurred locally (Sidi Bouzid region) on this platform.

In central (except the western part) and southern Tunisia, above the Aptian-Albian unconformity, the *Fahdène/Zebbag* series can be subdivided into two third-order depositional cycles (sequences) the lower one of which is Middle to Late Albian-Vraconian in age whereas the upper is Early Cenomanian-Late Cenomanian *p.p.*. These cycles are differently recorded between northern (outer-shelf) and southern (inner-shelf) central Tunisia (Fig. 3).

III-1- Middle to Late Albian - Vraconian cycle

III-1-1- in northern central Tunisia (outer-shelf /basin transition)

In this area -which nearly covers the structural block bordered by the M'rhila fault in the north and the Gafsa fault in the south- the first depositional cycle overlying the Aptian-Albian unconformity corresponds to the upper term of the *Fahdène Formation upper shale Member* which is essentially Vraconian in age (*Planomalina buxtorfi* zone), except toward western central Tunisia (*i.e.* Jebel El Hamra area) where lower deposits of this cycle are Middle to Late Albian in age including in addition the uppermost levels of the *Fahdène Formation Middle shale Member*.

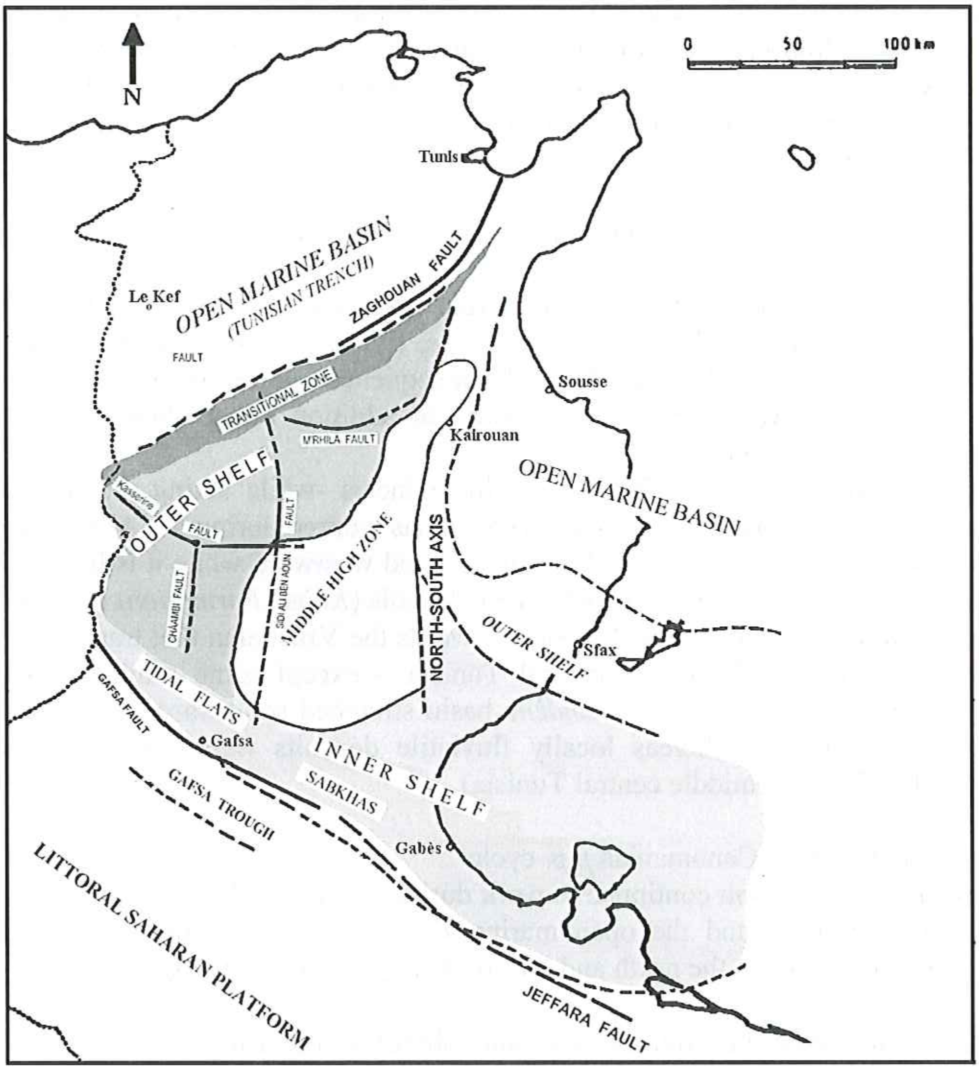


Fig. 3 - Main paleogeographic domains of central Tunisia during the Late Cretaceous

The Vraconian cycle includes trangressive and highstand systems tracts and is bounded above by a sub-aerial exposure surface correlatable with the global SB 96.5 MA (Haq *et al.*, 1988). The transgressive interval begins commonly by conglomerates and siliceous detritic material, followed by marls rich in ammonites and planctonic microfauna. Thickness of Vraconian marls is ranging from 30 m in the north to more than 200m in the south what supports the assumption of "southward tilting blocks" in central Tunisia (Boltenhagen, 1981; Chihi et Ben Ayed, 1987). Locally, these marls are characterized by organic matter and palygorskite clay mineral due to development of restricted muddy depressions (grabens) on the Late Aptian carbonate platform (Touir *et al.*, this meeting). The highstand systems tract determines a carbonate ramp (100m to 5m thickness range) which covers the whole central Tunisia while prograding on the previous muddy depressions before progressively thinning and then disappearing farther northward (basin). Locally (*i.e.* Jebel Semmama area), the ramp exhibits locally cross bedding and slump structures both inclined northward (basinward). At the end of the Vraconian cycle the ramp has finally emerged, whereas sedimentation should have continued in the north (basin).

II-1-2- in southern central Tunisia (inner-shelf)

In this domain which is mainly covering the structural block bordered by the Kasserine and Gafsa faults, the Vraconian cycle corresponds to the *carbonate lower cliff* of the *Zebbag Formation* which is unconformably overlying the emergent Late Aptian carbonate platform (*Orbata platform*). Deposition begins with thinning-upward alternating limestone and marls (transgressive interval) and ends by extension of the same carbonate ramp (highstand systems tract) already observed in the north. Sea level fall has finally led to dolomitization and sub-aerial exposure of the ramp.

II-1-3- in western central Tunisia (open marine domain)

In this sector of central Tunisia (*i.e.* Jebel El Hamra area) where the lower deposits above the Aptian/Albian unconformity are Early Albian *p.p.* in age, five depositional sequences have been defined (Echihaoui, 2004) such as the three oldest sequences started with transgressive systems tracts, whereas the two youngest ones show in addition either shelf margin or prograding lowstand systems tracts.

According to geographical distribution of Albian facies -while taking into account sequence stratigraphy data- it appears that central Tunisia has worked during the Albian times as emerged area bounded by the open sea both northward and westward while it is limited by the N/S axis structure to the east. Simultaneously, the paleosols (*Kébar Formation)* took place locally on this exposed and truncated area. It is only towards the Vraconian that transgressive waters should have conquered the whole central Tunisia – except some remaining high pinnacles in the N/S axis area – when the *Fahdène* basin stretched southward on the so far emerged Late Aptian platform, whereas locally fluviatile deposits were retained within incised valleys (i.e. Jebel Kébar, middle central Tunisia).

III- 2- Early Cenomanian – Late Cenomanian *p.p.* cycle

The central Tunisia platform continued to work during this interval between the *Saharan platform* to the south and the open marine *Tunisian trench* to the north, while showing outer and inner shelves in the north and the south, respectively (Fig. 3).

III-2-1- in northern central Tunisia (outer-shelf/basin transition)

The Cenomanian depositional cycle covers mainly the upper term of the *Fahdène Formation upper shale Member* (100 to 200 m) which includes transgressive and highstand systems tracts; the first one consists of a marl unit rich in both pelagic and benthic fauna where the maximum flooding surface (mfs) is to be found within the thin chalky-like limestone intercalations, whereas the second systems tract corresponds to the upper levels of this term that become more and more intercalated with lumachellic limestone.

III-2-2- in southern central Tunisia (inner-shelf)

The Zebbag carbonate platform having occurred in this area since the Vraconian has continued to work as a ramp also during the Cenomanian, its thickness ranges from nearly

800 m thick at the north of the Gafsa fault to less than 200 m at the south of the Kasserine fault beyond which the ramp is interrupted. This ramp which represents the whole Cenomanian depositional cycle in this region has first evolved within a subtidal environment during the transgressive interval and then under evaporitic conditions during the regressive stage. Indeed, the transgressive interval corresponds to the *lumachellic lower Member* of the *Zebbag Formation* (Burollet *et al.*, 1952-1954; M'Rabet *et al.*, 1995) which consists of bioclastic limestone succession intercalated at the bottom by marls and oyster-rich lumachelles. The highstand systems tract includes the *evaporate middle Member* of the *Zebbag Formation* (Burollet *et al.*, 1952-1954; M'Rabet *et al.*, 1995). The Cenomanian cycle was finished by emersion of the *Zebbag* platform the surface of which is abruptly overlain by fine-grained pelagic limestone (*Bahloul Formation* equivalent).

IV- LATE CENOMANIAN *P.P.* – LATE TURONIAN TO CONIACIAN DEPOSITS: *ALEG FORMATION* AND UPPER PART OF *ZEBBAG/FAHDENE FORMATION*

In northern central Tunisia these deposits include successively from bottom to top (i) the uppermost marl levels of the *Fahdène Formation* (Late Cenomanian *p.p.*) (ii) the *Bahloul Formation* equivalent (lower Early Turonian) and (iii) the whole Turonian part of the *Aleg Formation* (Burollet, 1956 ; Dali-Ressot, 1987); while in the southern central Tunisia they include successively (i) the *upper limestone Member* of *Zebbag Formation* (Burollet *et al.*, 1952-1954; M'Rabet *et al.*, 1995), (ii) the *pelagic limestone Member* (Razgallah *et al.*, 1994) which is coeval with the euxinic *Bahloul Formation* (Touir & Soussi, 2003), (iii) the carbonate *Gattar Member* and (iv) the whole Turonian part of the *Aleg Formation* which is relayed locally by the *Rouana Member* breccias.
Such successions determine two third-order depositional cycles separated by the Middle Turonian major unconformity; the lower one is Late Cenomanian-Middle Turonian in age whereas the upper one extends on the Middle Turonian –Late Turonian to Coniacian interval. These cycles are distinctively recorded between northern (outer-shelf/basin transition) and southern (inner-shelf) central Tunisia (Fig. 3).

IV-1- Late Cenomanian – Middle Turonian cycle

IV-1-1- in northern central Tunisia (outer-shelf/basin transition)

The depositional cycle starts within the uppermost marl levels of the *Fahdène Formation* which form with the overlying foliated pelagic limestone unit (*Bahloul Formation* equivalent) the transgressive systems tract (Touir & Soussi, 2003). These limestones are covering the whole Tunisia area and extending farther southward on the Saharan platform (Busson, 1970) while becoming particularly enriched in organic matter towards the basin domain in the north (Layeb, 1990; Robaszynski *et al.*, 1990) and locally within the intra-cratonic Gafsa trough in the south (Abdallah *et al.*, 1997) where they define the typical *Bahloul Formation*. Such widespread pelagic limestones are related to a rapid sea level rise having led during the Early Turonian to the drowning of the central Tunisia platform as reported in Saïdi et al. (1996); it was also responsible for a worldwide oceanic anoxic event (Hanckok & Kauffman, 1979; Jenkyns, 1980).

The highstand systems tract can be subdivided into early and late parts; the first one (Early Turonian) corresponds to the ammonite-rich marls forming the lower part of the *Annaba Member* whereas the second (Middle Turonian) includes successively (i) the upper part of the last *Member* that shows benthic fauna-rich marls and limestone intercalations and (ii) the lower term of the *Biréno Member* that displays a rudist-bearing rimmed carbonate platform. The cycle ended by emersion of this platform and development of a major unconformity correlatable with the global SB 91.5 MA on which are laying transgressive breccias and limestones of the following cycle.

IV-1-2- in southern central Tunisia (inner-shelf)

In this area the Late Cenomanian-Middle Turonian depositional cycle also starts with transgressive deposits represented by the *upper limestone Member* of the *Zebbag Formation* such as the maximum flooding surface (mfs) is to be placed within the *pelagic limestone Member*. The overlying *Gattar Member* which determines a northward-dipping carbonate ramp (Touir & Soussi, 2003) materializes the early highstand systems tract of the cycle while the late one exhibits different facies due to local synsedimentary tectonic movements as reported in many works (Chihi *et al.*, 1987; Boukadi *et al.*, 1990; Ben Ayed, 1993; Bouaziz *et al.*, 2002). Indeed, from north (Sidi Bouzid region) to south (Gafsa region) occur respectively (i) laminated algal dolostones intercalated by many collapse breccias levels associated to anhydritic matrix (*Rouana Member*) indicating a tidal environment (ii) nearly 100m thick anhydrite mass (*Beïda Member*) corresponding to a wide evaporitic zone on the northern and western borders of which developed (iii) rudist-bearing limestones (*Boudouaou Member*). Farther to south – beyond the Gafsa fault – the highstand also consists of evaporates and tidal carbonates. The depositional cycle ended by emersion of the whole central Tunisia inner-shelf due to a major sea level lowering correlative with the global SB 91.5.

Particularly, in middle central Tunisia (high zone) eustasy was coupled both with local tectonic and halokinetic movements (Ben Brahim, 1983; Boukadi & Bédir, 1996) what have resulted in southward tilting of the sedimentary floor between the Gafsa and Kasserine faults (Boltenhagen, 1981; Châabane, 2005). The resulting resistant emerged area experienced collapse brecciation of dolomitic intercalations due to dissolution of associated anhydrites by meteoric waters, while occur locally some pedogenetic horizons (Châabane, 2005).

IV-2- Middle Turonian– Late Turonian to Coniacian cycle

Toward northern Tunisia (basin domain) this depositional cycle covers approximately the lower half of the marly *Kef Formation* whereas in central Tunisia and farther to south (platform domain) it extends on different *Members* of *Aleg Formation*. Indeed, in northern central Tunisia (outer-shelf to basin transition) this cycle includes from bottom to top (i) the *Biréno* upper term (10 m), (ii) the "*marnes inférieures de l'Aleg*" *Member* (100 m) and (iii) the *Douleb Member* (40-70 m). In the southern central Tunisia (inner-shelf domain) the cycle also covers different units of the *Aleg Formation* including from bottom to top (i) a rudist-bearing carbonate term (equivalent of the *Biréno Member* upper term), (ii) the *shaly Member* (equivalent of the "*marnes inférieures de l'Aleg*" *Member*) and (iii) the lower *gypsum Member* (equivalent of the *Douleb Member)*. Nevertheless, in Sidi Bouzid region (middle high zone) the Turonian cycle corresponds approximately to the upper half of the breccias-rich *Rouana Member*. While going farther to south -beyond the Gafsa fault- the same depositional cycle is dominated by tidal carbonates associated to evaporates and rarely terrigenous detritic intercalations except locally (*i.e.* intra-cratonic Gafsa trough) where rather occur deep-water facies.

In central Tunisia, the present depositional cycle includes transgressive to shelf margin and highstand systems tracts which are distinctively recorded according to considered regions (Fig. 3).

IV-2-1- in northern central Tunisia (outer-shelf/basin transition)

On the northern border of the preceding *Biréno* platform, the Middle Turonian-Late Turonian to Coniacian depositional cycle begins with a shelf margin to transgressive systems tract illustrated by ooid-rich limestone succession that exhibits locally basinward-dipping cross stratification and slumps. While going southward, the marine transgression resulted first in reworking of the *Biréno* platform surface followed by development of a widespread rudist-bearing carbonate unit. Transgression has continued by deposition of thinning-upward alternations of marls and carbonates whose thickness is increasing from M'rhila fault (50 m) to the Kasserine one (more than 150 m). The highstand records start with thickening-upward alternations of marls and lumachelles and continue by the *Douleb* carbonate ramp which commonly exhibits northward-dipping cross stratification and slumps. This prograding ramp has filled-up -toward the Late Turonian- the whole depositional areas in central Tunisia and stretched on the N/S axis high zone too. While going toward northern Tunisia (basin), the *Douleb* ramp becomes progressively thinner before disappearing farther to north within the *Kef Formation* marls. Toward the Coniacian, the ramp has emerged in almost the whole central Tunisia engendering a major unconformity correlatable with the global SB 88.5 MA (Touir & Zaghbib-Turki, 2004).

IV-2-2- in the middle central Tunisia (high zone)

This middle sector of central Tunisia experienced simultaneously -during the low Early Turonian- tectonic uplift and southward tilting and then has worked as a low subsident high zone which was periodically emerged (Châabane, 2005). It covers a nearly 2000 km^2 wide area framed by three major faults: Kasserine and Gafsa faults, respectively to the north and the south and Sidi Ali Ben Aoun fault to the west; it also extends eastward on the N/S axis zone. In such shallow-water area, transgressive deposits of the Middle Turonian – Late Turonian to Coniacian cycle consist of subtidal pellet-rich limestone and thin marl intercalations (15m) while the highstand is illustrated by tidal para-sequences (10 m) associated to flaser-bedding structures. The cycle is capped by a sub-aerial exposure surface marked by epikarsts and ferrous encrustations which can be regionally correlated with the *Douleb* platform surface and globally with the SB 88.5 (Châabane, 2005).

IV-2-3- in southern central Tunisia (inner-shelf)

This domain has worked essentially as a wide evaporitic system located at the south of the previous high zone and extends farther southward beyond the Gafsa fault, where it becomes locally relayed by tidal environments. Even so, it is possible to distinguish a transgressive interval represented by some thinning-upward alternations of bioclastic limestone and organic matter-rich marls and a highstand which corresponds to a series of filling-up evaporate para-sequences. The depositional cycle is capped by an emergent surface which can be also correlated with the global unconformity SB 88.5 MA. Above, lay the Coniacian to Santonian transgressive marls and limestones forming the so-called *"marnes supérieures de l'Aleg" Member*.

V- CONCLUSIONS

In central Tunisia area (southern Tethyan margin), the Cretaceous sedimentary history is marked by an important stratigraphic gap mainly covering the Early Albian to Middle Albian *p.p.* interval while defining a major unconformity generalized at least along the whole central

Tunisia. Above this unconformity the lithostratigraphic stacking preserves the following prominent features:

- ✓ Sedimentation has engendered many transgressive/regressive depositional cycles usually bounded by emergent surfaces which are correlative with global sequence boundaries. Such unconformities were controlled by both global sea level falls and local tectonic and halokinetic movements.

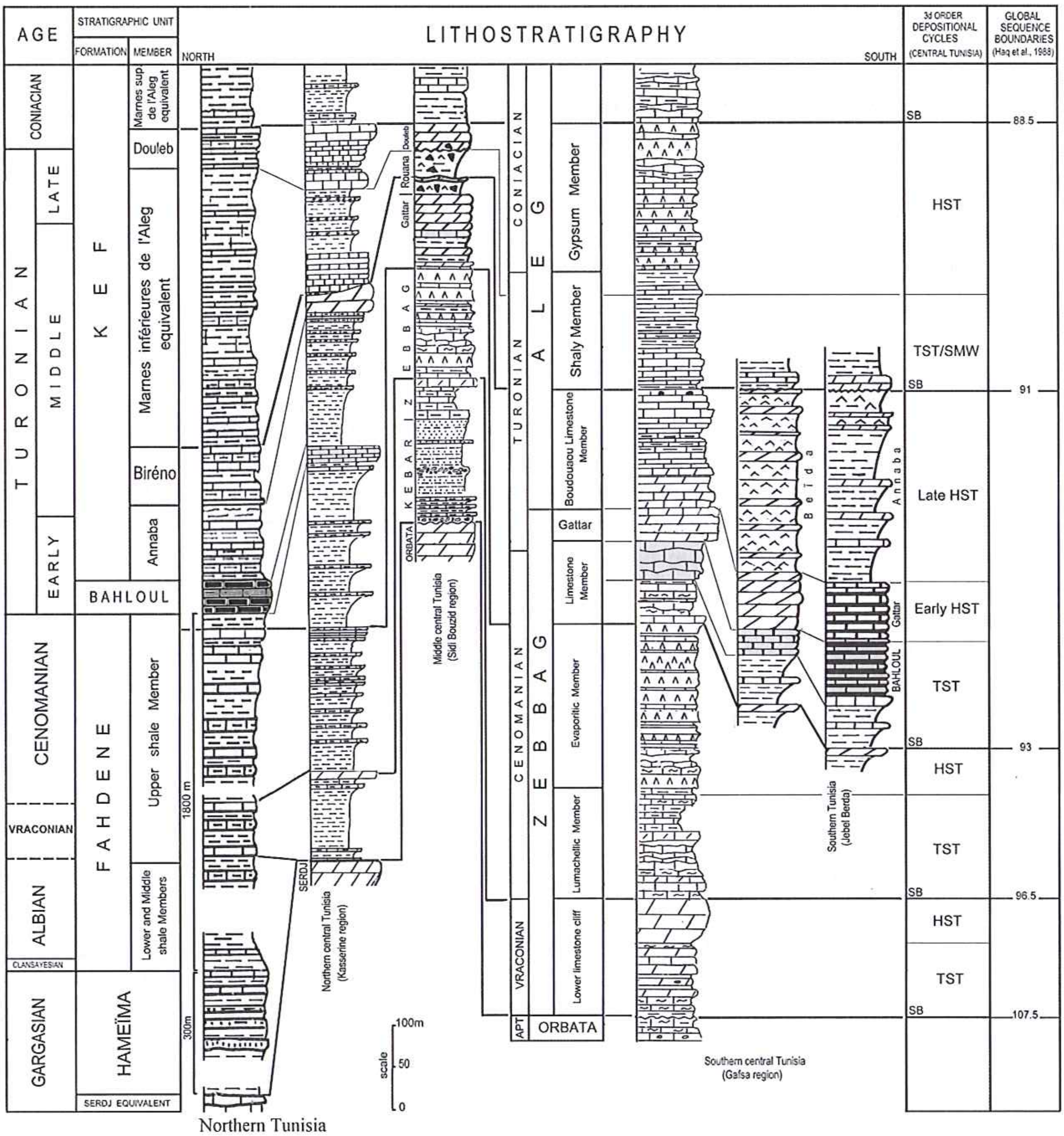


Fig. 4 - Main characteristic sections in central Tunisia Late Cretaceous outcrops compiled from Burollet et al., 1952-1954; Touir et al., 1989; Zghal, 1994; Abdallah & Meister, 1997; Touir & Soussi, 2003) and inferring third order depositional cycles.

- ✓ Various carbonate platforms developed depending on eustatic regressive phases but whose geometry and spatial extension were further controlled by local tectono-structural framework. These consist respectively of (i) *Zebbag/Gattar* ramp -the lower part (Vraconian) of which covered the whole central Tunisia whereas the upper one (Cenomanian) was limited to the north by the E-W Kasserine fault- (ii) *Biréno* rimmed platform (Middle Turonian) between M'rhila and Kasserine E-W faults and (iii) prograding *Douleb* ramp (Late Turonian) which has covered the whole central Tunisia and extended farther to north within the open marine *Kef* basin.

- ✓ An outstanding euxinic facies (*Bahloul Formation* source-rock) occurred depending on the low Early Turonian rapid sea level rise and the associated worldwide oceanic anoxic event.
- ✓ Tow continental formations including pedogenetic horizons have also locally marked the post-Aptian series, respectively during the Late Aptian to Early Albian (*Kébar Formation*) and the Middle Turonian (*Rouana Member*), due to contemporaneous relatively high amplitude of sea level fall where local tectonic and halokinetic-related uplift have intervened with eustasy.

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THE LOWER CRETACEOUS OF CENTRAL TUNISIA

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The Lower Cretaceous of central Tunisia

In Tunisia one of the most important new idea for the tunisian Cretaceous series was the definition of a great number of formations by Burollet (1956), completed by M'rabet (1981). For the first time in this country, lithostratigraphic units were proposed while at that time french geologists used only biostratigraphic ones. The introduction of lithostratigraphy seems to be more usefull for regional coherence as Cretaceous tunisian series lack generally of fossils. Imediately, success was very important, firstly for petroleum compagnies, especially the " seven sisters " which use lithostratigraphy since a long time, secondly for the tunisian geologist community which increases very quickly in the following decades.
Nevertheless, during the seventies and eighties, the usual
was to use progressively these lithologic units as biostratigraphic ones: ages were attributed to formations, in some cases with paleontological datations, but generally without prooves. This way was not in accordance with stratigraphic rules and lead to confusions as for regional correlations as for paleogeographical knowledges. It is the reason why we propose only to define characters and ages of formation in their type-localities, then to discuss briefly problems of regional correlations.

1. – FORMATIONS IN THEIR TYPE-LOCALITIES

1.1. Sidi Khalif Formation

1.1.1. Definition and type-localities

The Sidi Khalif Fm was defined by Burollet (1956), then completed by M'rabet (1981). It rests conformably on the calcareous Nara Fm (Upper Jurassic) or on his marly lateral equivalent and is is generally overlain by dolomites and sandstones of the Meloussi Fm (fig. 1). Sidi Khalif Fm consists of shales and grey or black marls (green or bluish weathering colors). Interfingering limestones and sandstones beds are frequent. The basal part of this formation is characterized by marl-limestone sequences bearing Ammonites and Calpionellids, and in the upper part shales and bioclastic limestones intercalations. Siliciclastic silts occur as well at the bottom as at the top of the formation.
Lithostratotype was proposed by Burollet (1956) in the Djebel Sidi Khalif section (fig. 3). Later, M'rabet (1975, 1981) choose a more complete and best exposed section on the western edge of Tellet el Korchef, in the northern part of the Djebel Nara (fig. 2 and 3).

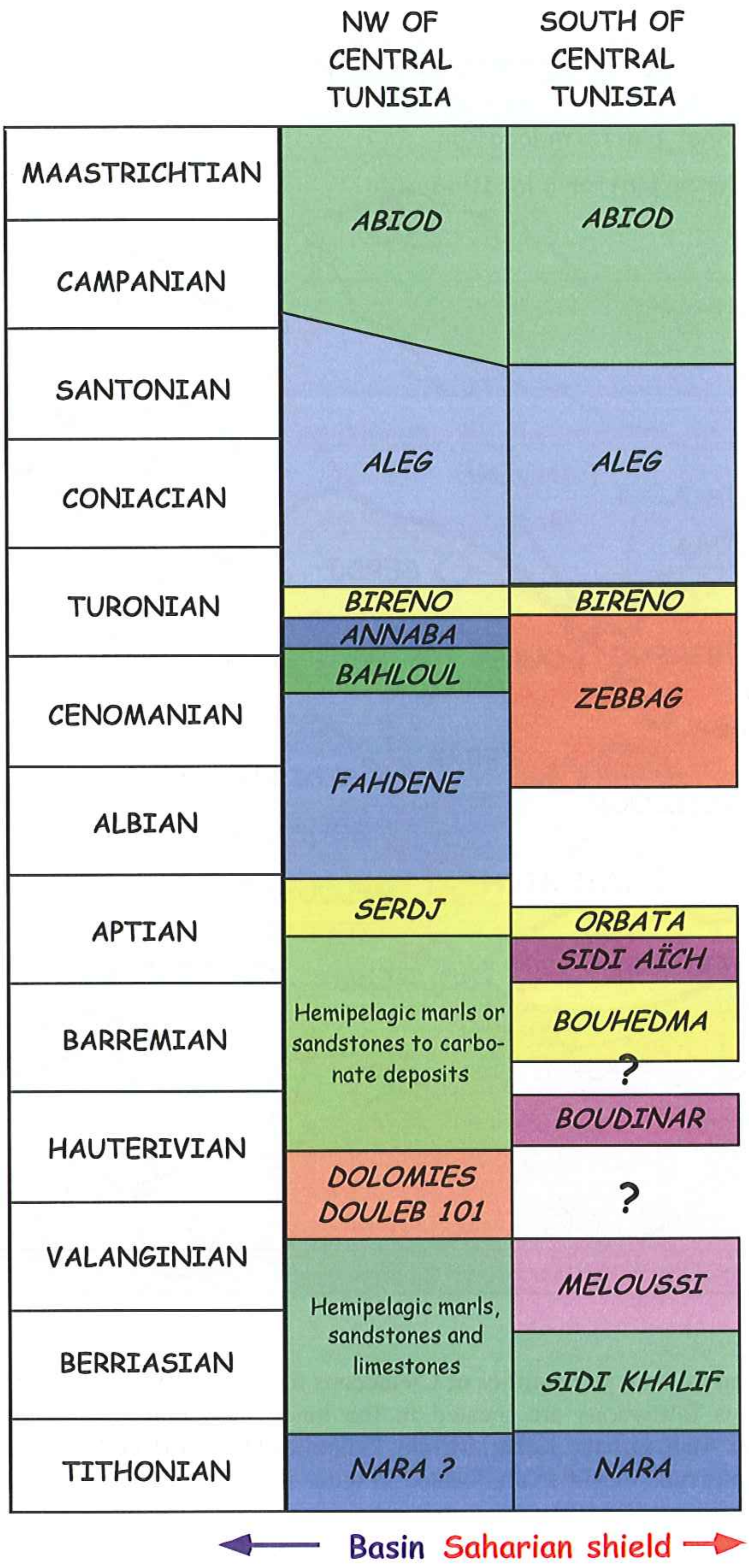

Fig. 1.– The main lithologic formations of the Tunisian Cretaceous series.

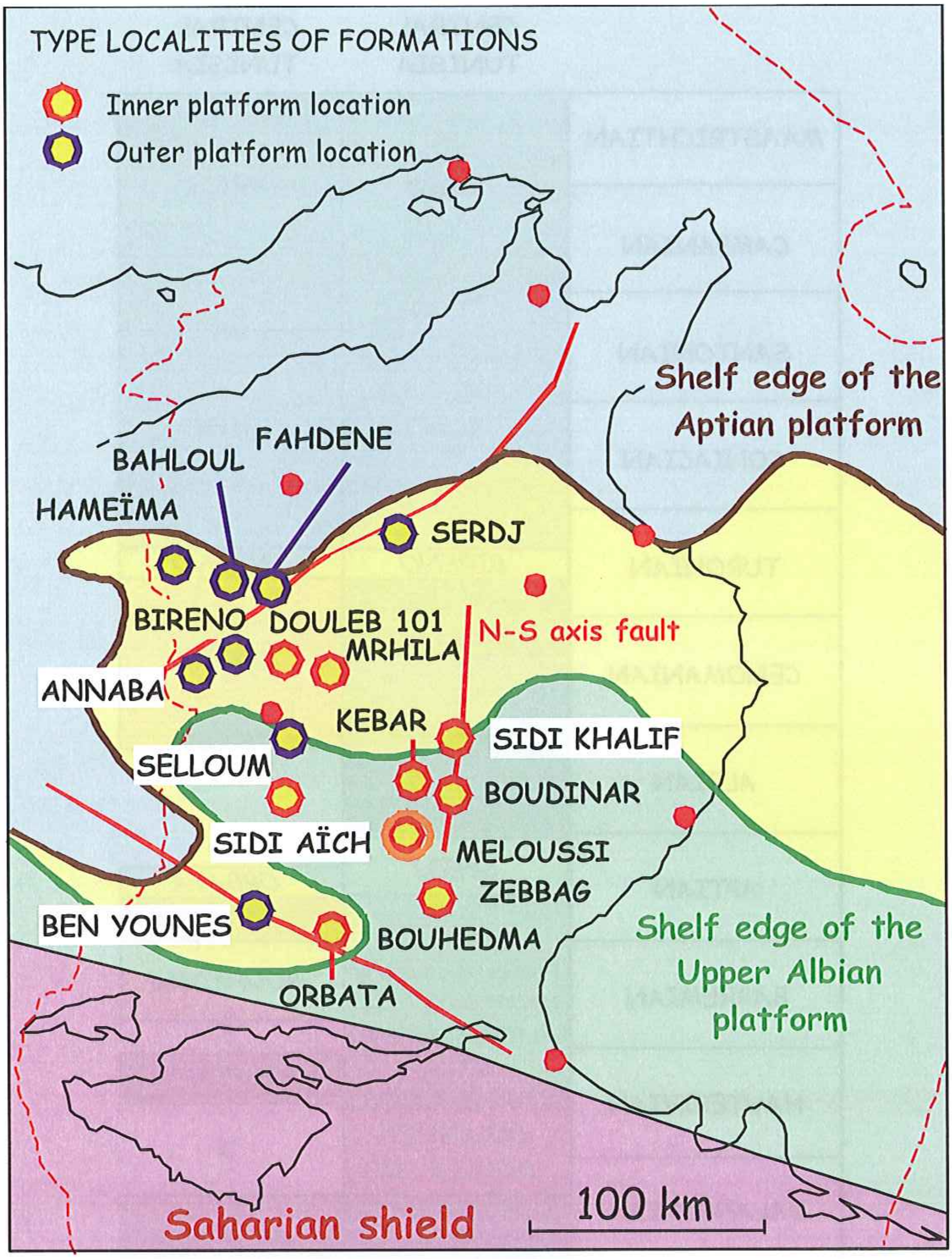

Fig. 2.– Location of the type localities of Cretaceous formations. Most of the type localities of early Cretaceous formations are located in the inner shelf domain (Meloussi, Boudinar, Bouhedma, Sidi Aïch, Orbata, Kebar, Mrhila, Dolomies Douleb 101). In the other hand, most of late Cretaceous type localities are located in outer shelf or basin domain (Annaba, Bireno, Ben Youssef, Fahdene, Bahloul).

In the type area, thicknesses vary from 120 m (Djebel Kebar section) to 290 (Djebel Nara section). Northwards, the series attributed locally to Sidi Khalif Fm is 2770 m thick in hole OBL. 101 (Oued Bahloul).

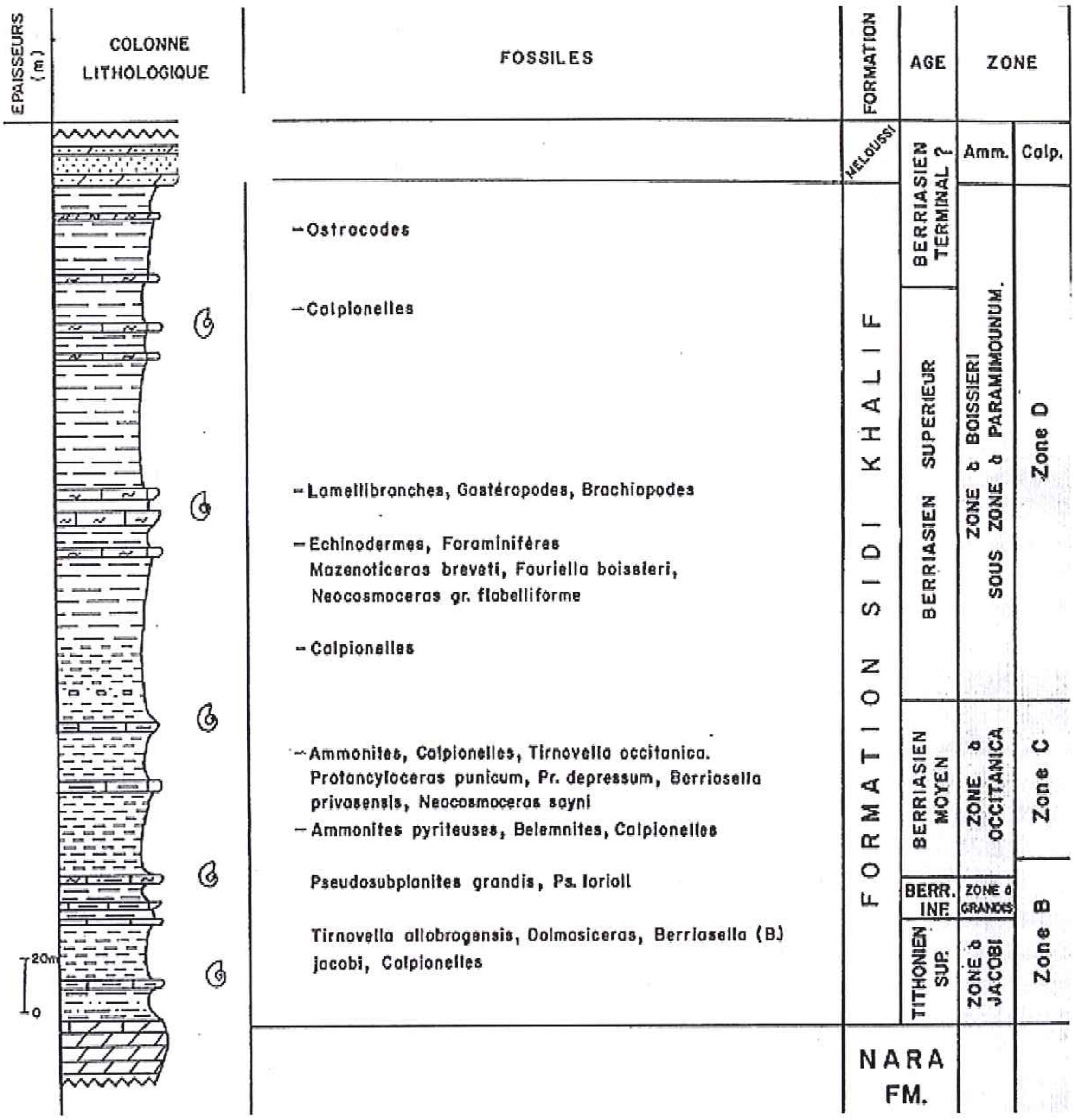

Fig. 3.– The Sidi Khalif Formation in the Djebel Nara section (M'rabet *et al.*, 1995).

1.1.2. Biostratigraphic datations and interpretation

Sidi Khalif Fm is late Tithonian to Middle Berriasian in age in the Djebel Nara section (Busnardo ; M'rabet, 1981).

– Late Tithonian is characterized by *jacobi* zone ammonites, B zone Calpionellids and the Ostracod *Oligocythereis tarhitensis* (primitive forms).

– Lower Berriasian age is given by grandis zone Ammonites (*Pseudosubplanites grandis, Ps. lorioli*), B zone Calpionellids and the Ostracod *Pontocyprella hodnaensis*.

– Middle Berriasian is characterized by *occitanica* zone Ammonites, C zone Calpionellids and Ostracods *P. hodnaensis, Protocytherella tuberculata* and *Protocythere* aff. *mazenoti* (A type).

□ Upper Berriasian is characterized by *paramimounum* zone Ammonites, D zone Calpionellids and ostracods (*Oligocythereis tarhitensis* [forme évoluée] and *Pr.* aff. *mazenoti* [B type]).

– The top of the Sidi Khalif Fm shows only two Ostracod species: *O. tarhitensis* (forme évoluée) et *Pr.* aff. *mazenoti* (B type).

The C morphotype of *Pr.* aff. *mazenoti* which characterize the latest Berriasiean and the earliest Valanginian in Algeria (Lamoricière and Tlemcen mountains, Donze, 1974) do not exist in the Djebel Nara section. For this reason, the lack of these species in Tunisia is an argument to propose that the age of the Sidi Khalif Fm is not younger than the Upper Berriasian middle part although M'rabet (1981) think without prooves that it could be latest Upper Beriasian or earliest Valanginian.

1.1.3. Environments

The basal part of the Sidi Khalif Fm corresponds to prodeltaïc (M'rabet, 1981), relatively deep, quiet and open marine environments with abundant planktonic and poor benthonic associations. Marly sediments are predominant but some silty or sandy levels exist. In the upper part of the formation, environments are shallower; sediments are represented by marly and silty or sandy levels. Planktonic organisms disappear progressively towards the top as benthic associations are abundant.

1.2. Meloussi Formation

1.2.1. definition and type-locality

The meloussi Fm, defined by Burollet (1956), is made of interfingering of white, fine-grained sandstones, green or beige silty clays, redish sandy dolomites, oolithic, dolomitic and/or bioclastic limestones and brown sandstones. Clays and sands correspond to particular sequences (fig. 4).
Type-section was proposed by Burollet (1956), then M'rabet (1981) inside the Djebel Meloussi area, Khanguet Zebbag series (fig. 2 and 4). There, Meloussi Fm is 452 m thick. Total thicknesses vary from 70 m (Djebel Siouf) to 1296 m in hole Douleb 101 5DL. 101)

1.2.2. Chronostratigraphic interpretation and depositionnal environments

The Meloussi Fm is undatable in its type-locality and surrounding region. Il was attributed to Hauterivian by Burollet (1956). Attending the datations of the underlaying Sidi Khalif Fm – datations which have been proposed later than the Burollet's work – the Meloussi Fm could be attributed to the Valanginian *pro parte* even if it is not impossible that its bottom could belong to the uppermost Berriasian.
The Meloussi Fm corresponds to deltaïc environments characterized by rythmic parasequences with shaly and sandy prograding bars at the bottom and channels infilling at the top. As siliciclastic inputs were not continuous, limestone levels are present into the series so that the general disposition of the Meloussi Fm appears to be rythmic. In the early Lower Cretaceous series, the Meloussi Fm appears to be transitional between the delta-front deposits of the underlaying Sidi Khalif Fm and the fluvial plain deposits of the overlaying Boudinar Fm.

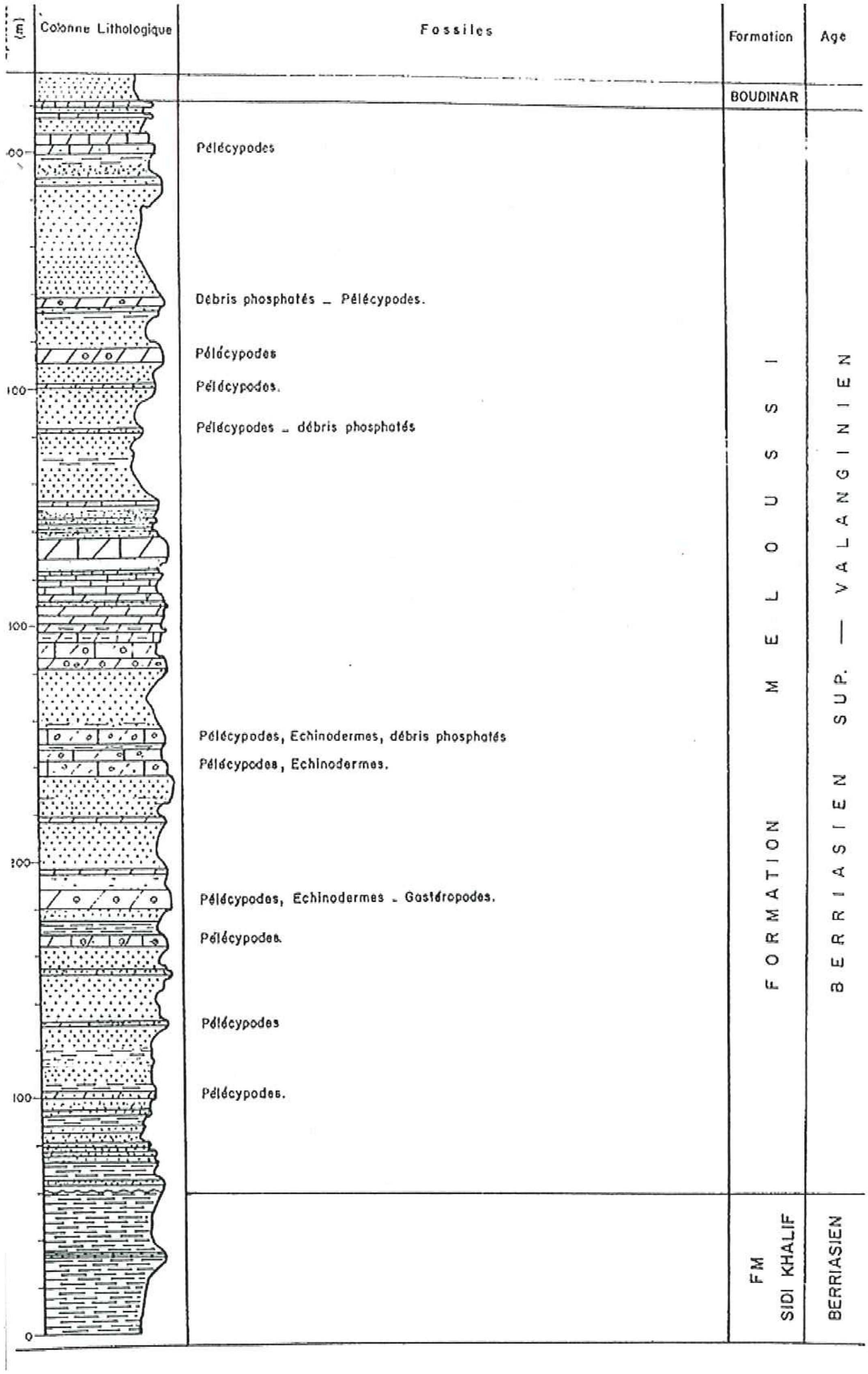

Fig. 4 .– The Meloussi Fm in the Djebel Meloussi section *In* M'rabet *et al.* (1995).

1.3. Dolomies de Douleb 101 Formation

1.3.1. Definition and type-locality

This massive and thick carbonate unit was for the first time recognized in hole Douleb 101 (DL. 101), between 2755 and 3552 m, by petroleum geologists of the SEREPT oil company, then published for the first time by Fournié & Pacaud (1973) and finally described by M'rabet *et al.* (1995). The formation consists mainly of thick, massive dolomites, locally with anhydrite noddles,

and silty shales with mica (fig. 2 and 5).
Hole DL. 101, NW from Sbeïtla and NE from Kasserine is the type-locality . Thicknesses vary from 797 in hole DL. 101 to 120 m in the Djebel Mrhila section.

1.3.2. Chronostratigraphy and interpretation

Dolomies de Douleb 101 Fm was deposited during Valanginian-Hauterivian time according to pollens and nannofossils (Fournié & Pacaud, 1973). *Choffatella decipiens*, *Nautiloculina* sp., *Lithocodium aggregatum* and *Cayeuxia* aff. *kurdistanensis*, which indicate post-Valanginian age, were identified in the Djebel Douleb and Djebel Semmama sections (Zghal, 1994). This formation exists only on the northwestern edge of the platform. It could be interpreted as a huge lowstand system.

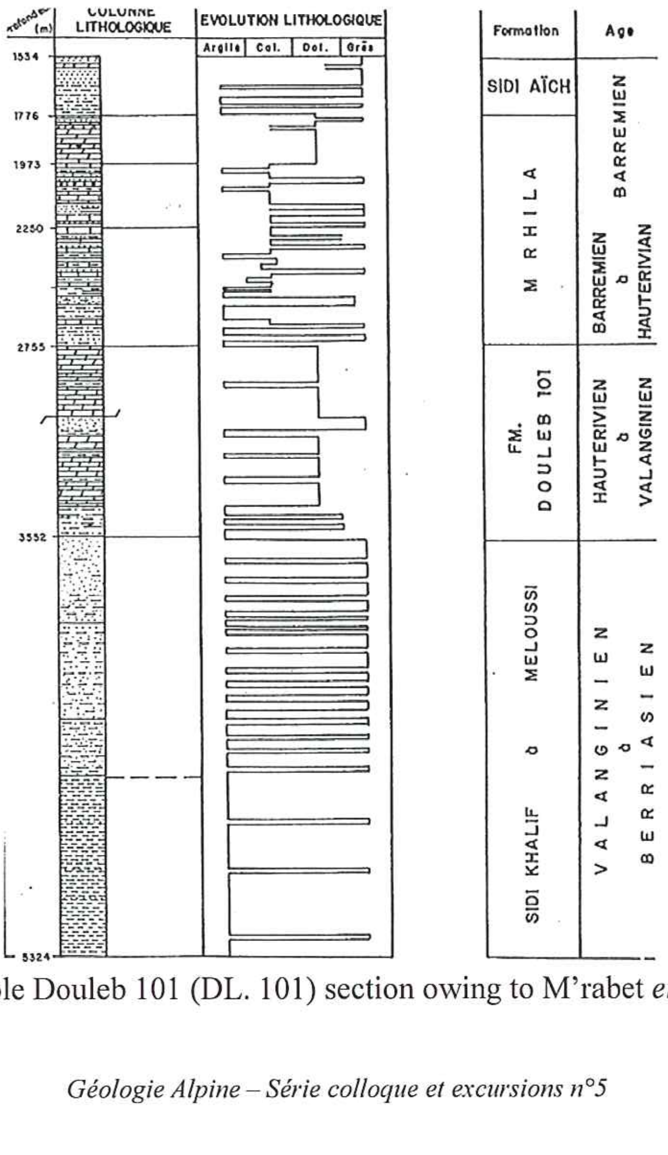

Fig. 5.– Hole Douleb 101 (DL. 101) section owing to M'rabet *et al.* (1995).

1.4. Boudinar Formation

The Boudinar Formation, defined by Burollet (1956) then M'rabet (1981), consists of a thick, white, coarse-grained, sandstone unit. In some places, color is yellowish or pink. Stratal pattern is not well expressed but irregular or cross-bedded stratifications occur frequently. Scarse shaly intervals exist into the sandstone unit. Sequences, deposited in fluvial or fluvial plain environments, are coarsening-up

séquences granodécroissantes à base ravinante et à stratifications obliques,

The WSW-ENE, 270 m thick type-section is located in the Djebel Boudinar area, between Djebel Seugdal and the central part of Djebel Boudinar (fig. 2). Thicknesses vary from 40 m (south of the Djebel Nara) to 410 m (hole Souina 1 [SO.1]).
On the chronostratigraphic point of view, the Boudinar Fm was attributed firstly to Barremian- ? Aptian age by Burollet (1956). Nevertheless, until today, the age of the Boudinar Fm is not established, as emphasized by M'rabet (1981) who have proposed that the top of the formation could be attributed to Hauterivian-earliest Barremian. Later, Hauterivian-early Barremian age was proposed by Burollet *et al.* (1983), always without prooves.

1.5. Bouhedma Formation

The Bouhedma Formation, defined by Burollet (1956) then M'rabet (1981), is a mixed, siliciclastic and limestone unit characterized by the alternation of fine-grained sands or sandstones, shales, limestones (locally oolithic and bioclastic limestone) and laminated dolomites. Evaporitic beds (gypsum) occur in some places (fig. 6 and 7).
Type-locality was proposed by Burollet (1956) in the Djebel Bouhedma section where the formation is 160 m thick. An another 550 m thick type-section was later proposed by M'rabet (1981) in the Djebel Meloussi.
The undated Bouhedma Formation was firstly attributed to Barremian by Burollet (1956). M'rabet (1981) think that this formation is Barremian and Lower Aptian pro parte, attribution which is also proposed by Burollet *et al.* (1983). From the Chotts region to Sidi Bou Zid, sedimentation have been refered to tidal flats and sebkha environments.

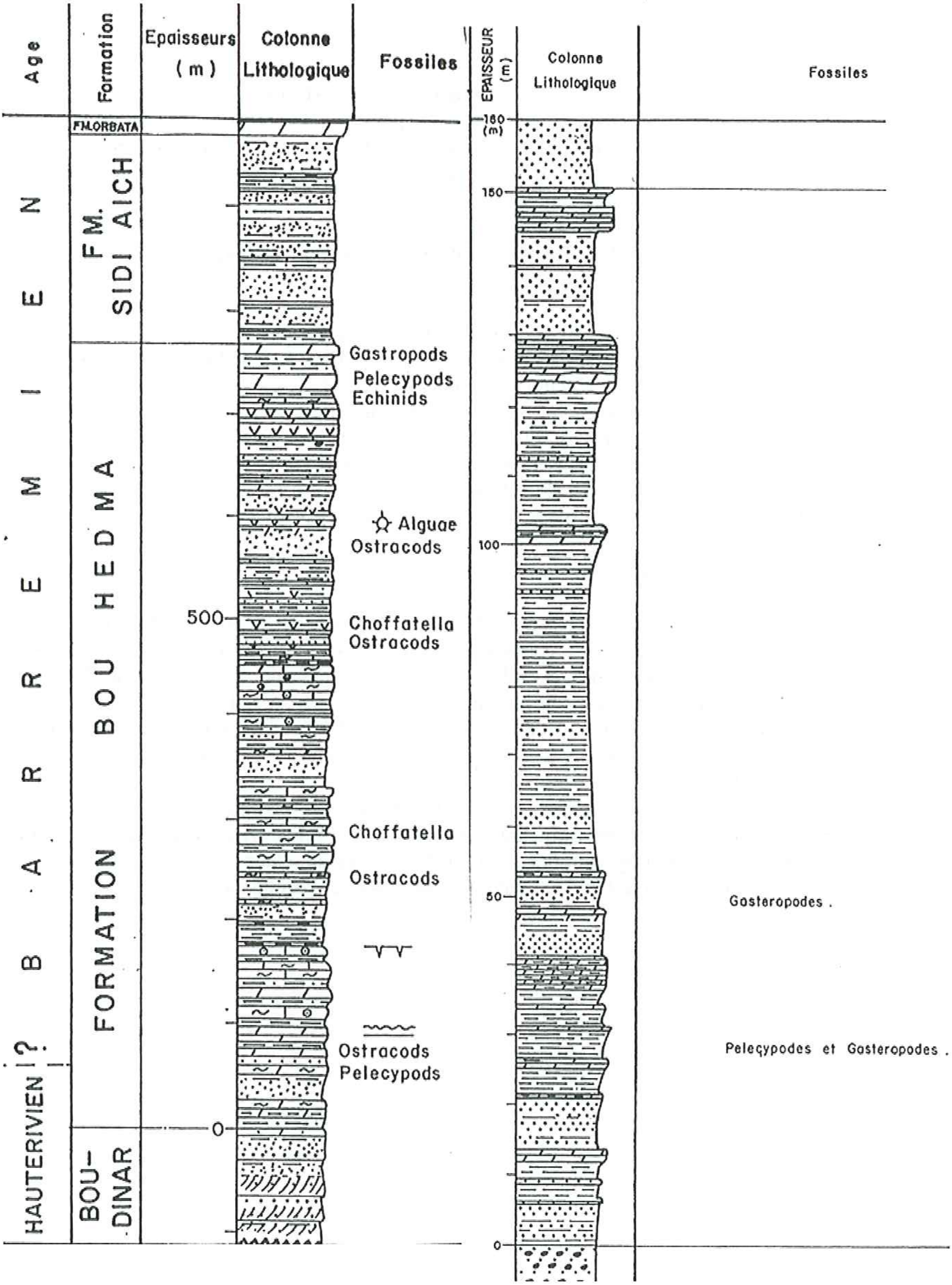

Fig. 6-7.– Bouhedma Formation in the Djebel Bouhedma (right) and Djebel Sidi Aïch (left)

1.6. Marnes du Mrhila Formation

The Marnes du Mrhila Formation consists of thick marl and green clays levels separated by thin bioclastic and clayey limestone beds overlaying by massive dolomites, marls and sandstones

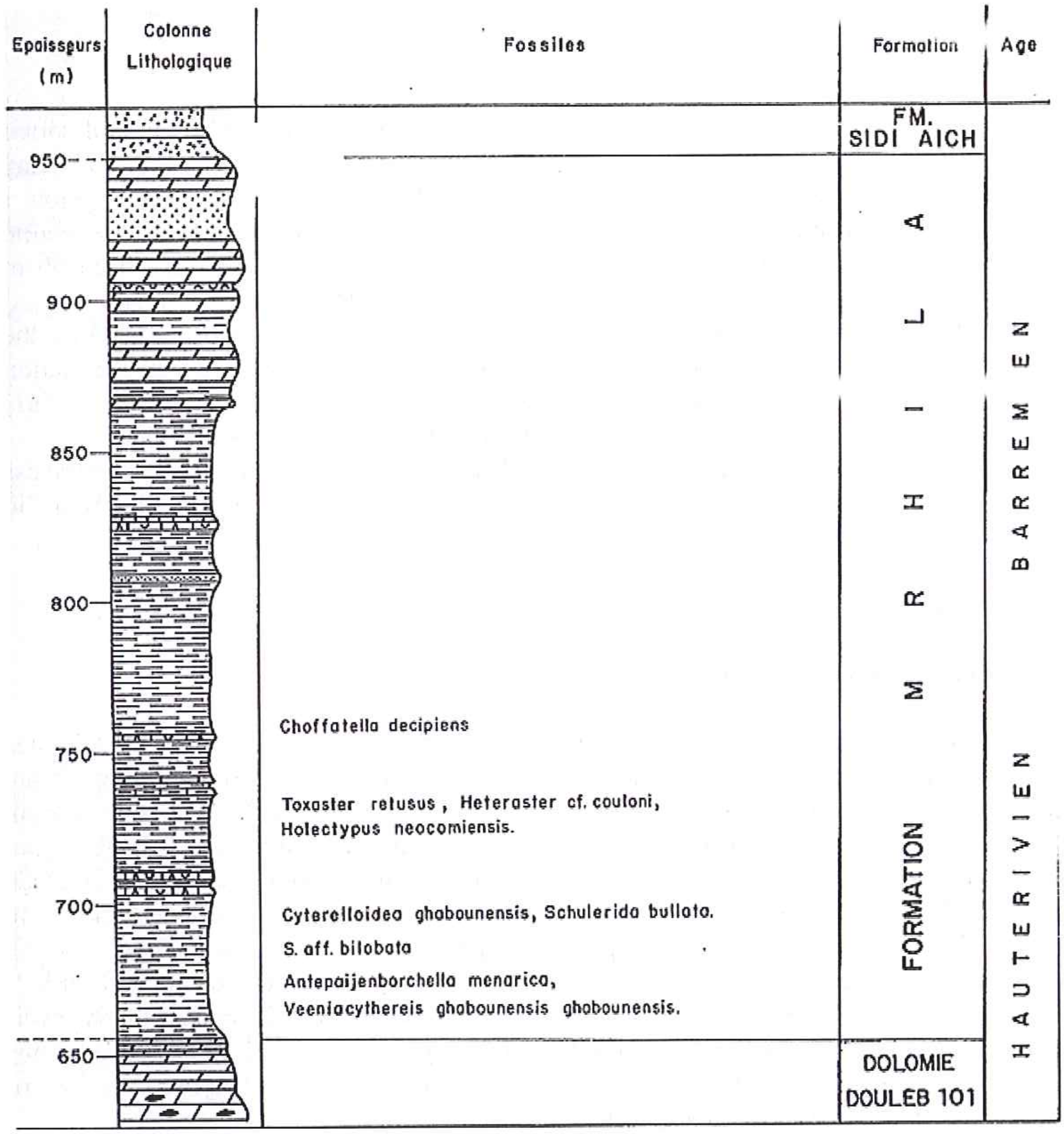

Fig. 8.– The Marnes du Mhrila Fm in the Djebel Mrhila type-section, owing to M'rabet *et al.* (1995).

An oblique stratification

(fig. 8). The type-locality is located in the northern part of the Djebel Mrhila (fig. 7).
Lower Aptian (Bedoulian) age was proposed by M'rabet (1981) for the Marnes du Mrhila Fm but Damotte *et al* (1987) and Zghal (1994) give good paleontological data for late

Hauterivian-early Barremian age, according to abundant foraminifer and ostracod associations.
In the Kasserine –Sbeïtla region (Djebel Chambi, Djebel Mrhila, holes SEM. 101, DL. 101 and OBL.101) sediment were deposited in shallow, warm and quiet infratidal environments of the photic zone. In the upper part of the formation, environments were shallower and less quiet. These environments correspond to an open marine situation on the early Cretaceous ramp.

1.7. Sidi Aïch Formation

This formation, defined by Burollet (1956), consists of white or greyish, fine, well-sorted sands. Sands are locally coarse-grained and redish. Silty clays and limestone thin beds may occur in some places. This sandy unit is known from the Chotts area to the Kasserine region.
Type-locality was choosen by Burollet (1956) in the Djebel Sidi Aïch, Oued el Kdaou section (fig. 2). Sidi Aïch Fm is 210 m thick in its type-section, but thicknesses vary from 60 m (Djebel El Hafey-Djebel Bouhedma sections) to 243 m in the hole DL. 101.
In the Djebel Serdj series, sandstones reported to the Sidi Aïch Fm have been dated by the Lower Aptian (Bedoulian) *Palorbitolina lenticularis* and *Choffatella decipiens* association (Tlatli, 1980). Later, this Lower Aptian (Bedoulian) age is also accepted by Mrabet (1981) since late Barremian age is proposed by Zghal (1994) for the Kasserine-Sbeïtla region.
Sediments of the Sidi Aïch Fm were deposited in shallow marine environments. Nevertheless redish sands and paleosoils refer to fluvial to continental environments in the Sidi Bou Zid and Djebel Kebar sections.

1.8. Serdj Formation

1.8.1. Definition and type-locality

The Serdj Formation was defined by Burollet (1958): " il s'agit de calcaires et dolomies massifs, pouvant présenter quelques intercalations gréseuses dures. Cette formation représente des dépôts récifaux ou subrécifaux et contient généralement d'abondants fossiles se rapportant à ce faciès, en particulier des Rudistes, des Polypiers et des Foraminifères. " In the type-locality, Tlatli (1980) give us a good revision and complete description both for his Hamada Formation and for the Serdj Fm. Below the latest, marls and sandstones of the Hamada Fm contain fossils of " middle " Aptian age (uppermost Lower Aptian and earliest Upper Aptian). Above, in the Serdj Fm *sensu stricto*, Tlatli (1980) recognizes five calcareous units (Serdj 1: S1; Serdj 2: S2; Serdj 3: S3; Serdj 4: S4 et Serdj 5: S5) separated by clayey and marly levels (T1, T2, T3, T4) (fig. 8). In the Kasserine-Kairouan region, M'rabet (1981) sudivides the Serdj Fm in three membres – lower, middle and upper members, – the upper boundary of which corresponding to a subaerial exposition surface (fig. 9).
Type-locality of the Sedj Fm was defined by Burollet (1956), then by Tlatli (1980) in the Djebel Serdj, from Douar Sidi Hamada to the old mine). An another section was proposed by M'rabet (1981) in the Djebel El Hamra section, Kasserine area (fig. 10). Thicknesses vary from the maximum 1600 m Djebel Serdj section to 60 m.
An Aptian-Albian age was proposed by Burollet (1956) for the Serdj Fm, in the type-locality is due to Tlatli (1980) who gives biostratigraphic arguments for Upper Aptian (Gargasian) age. The same author propose also an earliest Albian age for the last sequence, but this proposition is only a possibility. In other places, M'rabet propose an late Aptian (Gargasian-Clansayesian) age for the Serdj Fm : early to middle gargasien for its lower member, late Gargasien to Clansayesian *pro parte* for its middle member (may be only middle Gargasian

locally for the basal part of this member) and Clansayesian *pro parte* for the upper member. In other points (holes of the Kasserine-Sbeïtla region), benthic Foraminifers, Ostracods and Algae of Upper Barremian-late Aptian (Gargasian) age exist into series reported to the Serdj Fm (Bismuth, 1973; Zghal, 1974). In the Djebel Serdj series, type-locality of the formation, sediments were deposited in shallow, open marine environments belonging to the shelf edge of the tunisian platform.

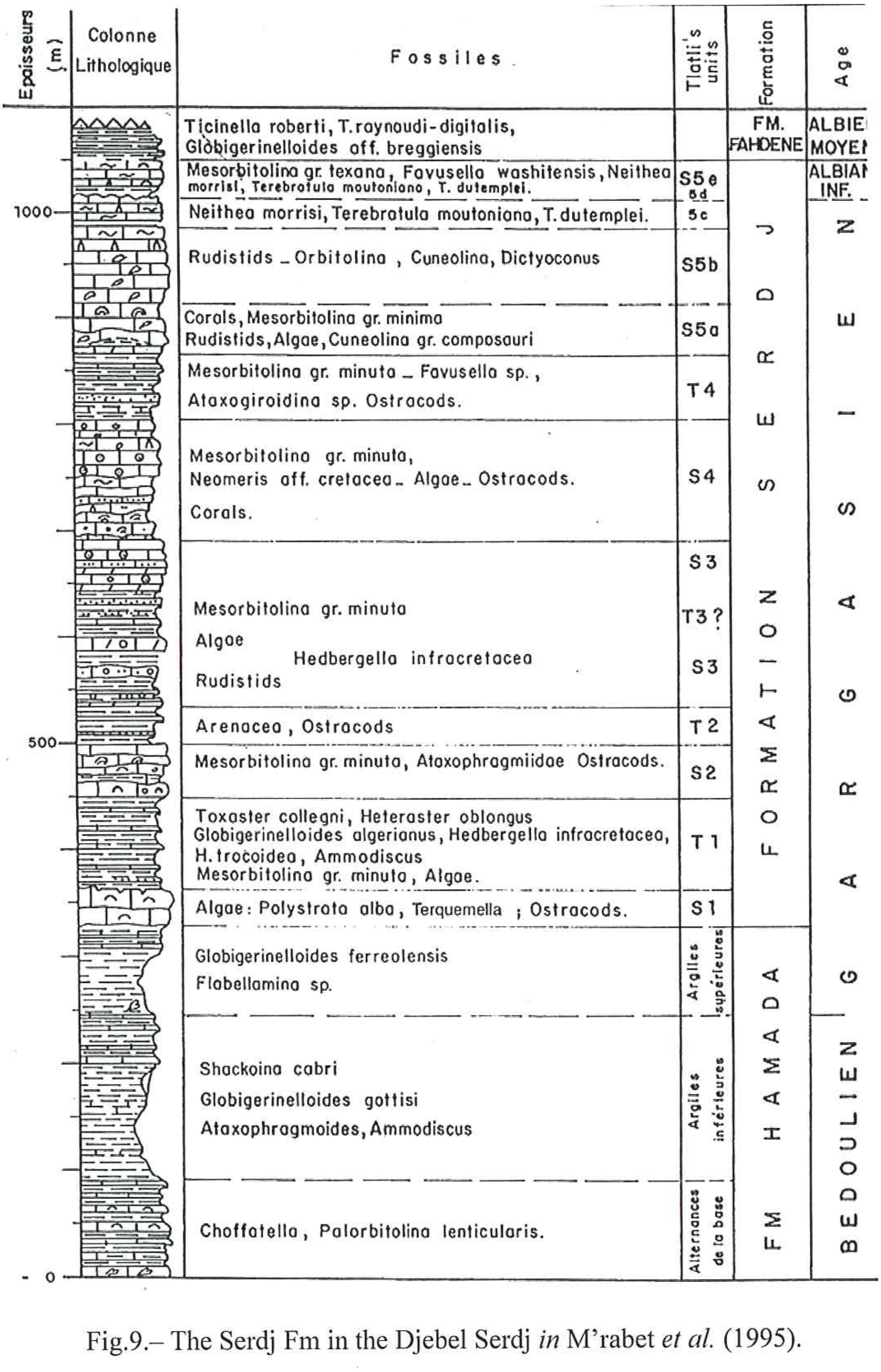

Fig.9.– The Serdj Fm in the Djebel Serdj *in* M'rabet *et al.* (1995).

1.9. Hameïma Formation

The Hameïma Fm, defined by Burollet (1956) is made of black or green clays intercalated by numerous and thick-size dolomites or bioclastic limestone beds. Orbitolina marls are frequent (fig. 2 and 11). The Hameïma Fm lies in between the underlaying Serdj Fm and the overlaying marls and clays of the Fahdène Fm. This sandy and dolomitic unit was interpretated by Burollet (1956) as the basal part of the Fahdène Fm. The Djebel Hameïma section, 310 m thick, corresponds to the type-locality.

On chronostratigraphic point of view, The Hameïma Fm belong to the upper part of Aptian, as proposed by Burollet (1956). Zghal (1994) propose an Upper Aptian age (late Gargasian to early Clansayesian) for two reasons: i) this unit lies between the Upper Aptian (Gargasian) Serdj Fm and a level dated by Clansayesian ammonites; ii) the most significant association of benthic foraminifers [*O. (M.) parva*] and Ostracods[*Rehacythereis zoumoffeni zoumoffeni, R. btaterensis imminuticostata, R. btaterensis interstincta*] characterizes the late Gargasian and the early Clansayesian.

Sediments of the Hameïma Fm were deposited on unstable and subsiding platform. Epineritic environments were welle developped with siliciclastic inputs, probably transported from soutwestern regions.

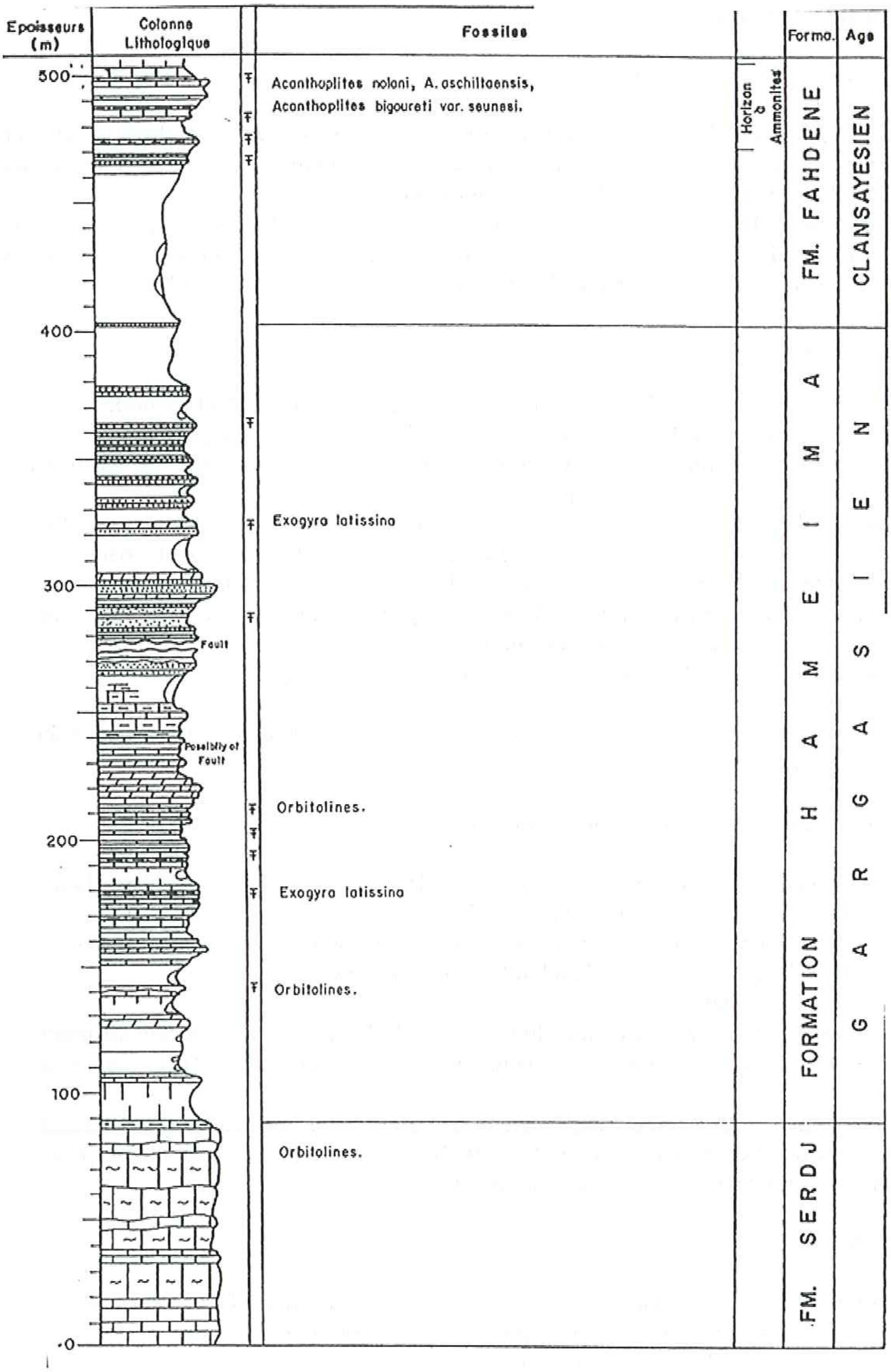

Fig. 11.– The Hameïma Formation in the Djebel Hameïma section, owing M'rabet *et al.* (1995).

1.10. Fahdène Formation

1.10.1. Definition and type-section

The Fahdène Fm, defined by Burollet (1956), i a very thick series made of clays, greyish or black marls, argillaceous limestone and limestone-marls bundles. In the Gara Hameïma section, Burollet (1956) suddivides the formation in four parts:

1) **Fahdène lower clays**, 328 m thick, made of clays, greyish or black marls, greenish at the bottom, interbedded with thin argillaceous limlestone beds. A few number of grauwackes level and some thick, grey limestone beds with fossils. Some beds looks like

Conglomérats monogeniques

Pyriteous Ammonites are abundant in the upper part, just below the Allam limestones.

2) **Allam limestone**: this 180 m thick unit corresponds to limestone and grey marls bundles. Fine-grained, black limestone have a white or greyish aspect due to weathering. Belemnites and Ammonites are frequent.
3) **Fahdène middle clays**, 300 m thick, are represented by greyish or black clays including numerous argillaceous limestone or thin, fine-grained, black limestone beds that having a white aspect due to weathering. Belemnites and Ammonites are abundant in the lower part of this unit. At the top, thin foliated limestone appear, known as the **Mouelha** foliated limestone, which is a regional reference horizon.
4) **Fahdène upper clays**, characterized by the lack of calcareous beds.

Type-locality corresponds to the hills which occur in the central part of the Oued Bahloul anticline, SE from Maktar.

1.10.2. Chronostratigraphic interpretation and environments

Fahdène Fm is late Aptian to Cenomanian owing to Burollet (1956). For the Gara Hameïma section, the same author gives the following precisions:
* Fahdène lower clays: Lower Albian and " zone de Clansayes " for the lowest part, corresponding to the Ammonites level and to the underlaying clays,
* Allam limestones: Middle Albian,
* Fahdène middle clays: Upper Albian including the early Vraconian (with albian affinities),
* Fahdène upper clays: Cenomanian, including the late Vraconian (with cenomanian affinities).
The Fahdène Fm is a thick series deposited in a marine, subsident basin characterized by infraneritic to bathyal environments (Burollet, 1958). According to the same author, presence of limestone beds may be due to climatic variations.

2.– DISCUSSION

Type-localities of the Tunisian early Cretaceous formations have been choosed in two different paleogeographic regions: the first package is located in the inner part of the platform (Sidi Khalif, Meloussi, Boudinar, Bouhedma, Sidi Aïch, Kebar, Orbata, Zebbag) and the second one on the shelf margin of the platform or in the basin (Dolomies de Douleb 101, Serdj, Marnes du Mhrila, Hameïma, Fahdène, Bahloul, Allam, Mouelha, Selloum, Ben Younès, Annaba, Biréno, Alleg). For this reason, the formations of the first package – except the Sidi Khalif Fm – do not contain fossils useful for datations, while the stratigraphic location of those of the second package is generally well known. For example, in Central Tunisia, none datation is available for Meloussi Fm and Boudinar Fm. Burollet (1956) was the first to propose a stratigraphic location in accordance with the presumed age of the underlaying and overlying formations, the age of which is also more or less unknown. As no more data are available since half a century, it is clear that several attributions could be possible, without any prooves. For the Boudinar Fm, propositions went from Hauterivian to Barremian-Aptian time. This lack of biostratigraphic knowledges is prohibitive for biostratigraphic synthesis or to propose good regional correlations onto platform series. Various authors attempt to clarify this situation but until today these studies are completely fruitless for three reasons: i) lithologic correlations based on the recognition of the different formations eveywhere on the platform, ii) general concept based on the erroneous idea that sedimentation is continuous on the platform, iii) general lack of modern sequence stratigraphy studies.

Lithologic correlations

On a general point of view, a sequence described in a section of the inner part of the platform changes laterally toward the basin so that platform facies are progressively replaced by deeper and more marine ones, without any similarities with those of the initial section. It is the reason why chronologic intervals observed in the outer part of the platform do not have any common character with that of formations defined in the inner part of the platform. On the other hand, formations are heterochronous units while their lithologic characters disappear progressively towards the basin : either lithologic units are used for stratigraphy and correlations are not possible or recognition of formations is more and more difficult towards the basin. It results that it is impossible to propose true paleogeographic or isopach maps.
An another problem is that all the authors want to recognize all the formations everywhere in Central Tunisia, including holes. As datations are relatively easy in the shelf margin series, the way of temptation lead to use these data for datation of formations defined in the inner platform series. Unfortunatly, this way is a confusing one. For example datations obtained for some levels of the Sidi Khalif Fm, Meloussi Fm or other formation in the Kasserine-Sbeïtla area could not be used neither for datations, nor for correlations with the same formations in their type-localities. In conclusion, datations and correlations by the way of lithologic formations are today as uncertain that during the Burollet's time, fifty years ago.

Gaps in Central Tunisia

During the two last decades, paleokarsts and huge subaerial exposure surfaces were discovered in different points into the Central Tunisia series. These discoveries imply that numerous gaps exist at different stratigraphical levels, some of them may correspond to long duration and important events. Gaps imply also that lithologic correlations become more hasardous than previously supposed. A good example is given by the Dolomies de Douleb 101 Fm, more than 600 m thick in its type-locality and known only in very thick outer platform series (djebels Mhrila, Douleb and Semmama). Elf-Aquitaine and SEREPT oil companies dated this formation with late Valanginian-Hauterivian pollens. For this reason it was very difficult to place this formation into the general stratigraphic scheme of Central Tunisia: as the sedilmentation in this region was supposed continuous where is the place of the Dolomies de Douled 101 Fm while Meloussi, Boudinar and Bouhedma Fm were deposited during a period which includes Upper Berriasian to Barremian times ? The answer to this question is so difficult that the Dolomies de Douleb 101 Fm was not represented by M'rabet (1981) and M'rabet *et al.* (1995). While the Meloussi Fm was presumably deposited during Hauterivian time (Burollet, 1956) and the Boudinar Fm during Hauterivian-early Barremian time (M'rabet, 1981; Burollet *et al.*, 1983), temptation is great to consider that Dolomies de Douleb 101 Fm is coeval with parts of the first one. This opinion was that of M'rabet, 1981, Damotte *et al.,* 1987 and Zghal, 1994. Unfortunatly, we have probably to reject this opinion for at least two reasons:

- It is difficult to think that carbonate platform deposits could be coeval with the huge siliciclastic sedimentation represented, in Central Tunisia, by the Boudinar Fm of fluviatil type;
- Important gaps exist during this period, highlighted by erosionnal surfaces at the top of the Meloussi Fm and of the Boudinar Fm in their type-localities (M'rabet, 1981; Soyer, 1987).

These erosionnal surfaces and paleokarsts emphasize important gaps during Neocomian time during at least two sea-level falls, perhaps due to climatic changes.
In our opinion, The Dolomies de Douleb 101 Fm seems to be at the good place during this particular period marked by Valanginian-Hauterivian boundary events which are well known in another regions of the Tethys. It is the reason why this formation appears as deposit belonging mainly to one or two Lowstand Systems Tracts. According to this hypothesis where is the location of the Dolomies de Douleb 101 Fm in comparison to that of Meloussi Fm and Boudinar Fm ? Two solutions are possible: either it corresponds to marine sedimentation during the emersion at the top of the Meloussi Fm or it is coeval to that of the top of Boudinar Fm (nevertheless, in the last case, Boudinar Fm was deposited before the late Valanginian and not during Hauterivian-Barremian time; this proposition is difficult today).
This discussion shows clearly that correlations are although impossible for the early Cretaceous series of Central Tunisia. Hard work have to be made before the proposition of a new and modern stratigraphic scheme.

Sea-level changes and tectonic unstability

Transgressive periods are more favourable to propose good lithologic correlations than regressive ones. Indeed, on the platforms, depositionnal environments are more regular during huge transgressions so that similar facies could be observed on very large region, tens of kilometers wide. Moreover, the large-scale open-marine environments lead to the development of some typical fauna associations onto the inner platform domain. Such is the case for the " middle " Cretaceous transgressions characterized by the drowning of the platform and the flooding of the northern margin of the Saharian shield: in Central Tunisia, correlations and datations of some levels are easyer, as for the basal part of the Zebbag Fm or for the Bireno Fm. Such seems to be the case of the middle part of Aptian time with the possible correlations from the basal part of the Serdj Fm and the Orbata Fm.
The last question is that of influence of tectonic unstability on the Cretaceous sedimentation. As in many other regions of the Tethys, it is very difficult to separate the relative parts of eustacy and tectonic unstability. In Central Tunisia, two main tectonic unstability periods are known, the first one at the Aptian-Albian boundary and the second at the Cenomanian-Turonian boundary. Despite the importance of these phenomenons – as discussed on the field-trip, – the tectonic unstability does not conceal the sea-level fluctuations which are very well observed in Tunisia as in many other regions of the Tethys.

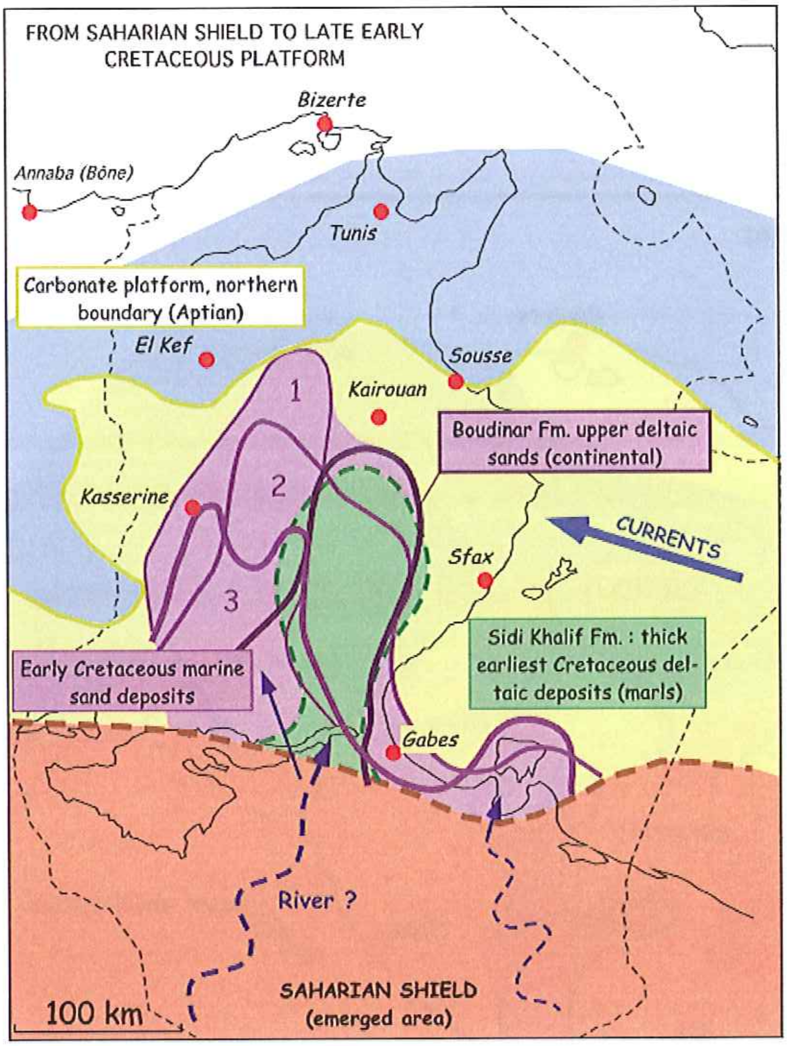

Fig. 12.– During Cretaceous time, Tunisia was a part of the southern margin of the Tethys, along the northern edge of the Saharian shield. Near the Jurassic-Cretaceous boundary, thick marly formation (Sidi Kralif Formation) was deposited in the central part of Tunisia ; these marls correspond probably to thin siliciclastic particles transported from the Saharian shield by rivers. From late Berriasian to Aptian time, several sandstone bodies are known in the early Cretaceous series, the most important of which corresponding to Boudinar and Sidi Aïch Formations. Nevertheless, these sandstone levels exist only on the western flank of the so-called North-South Axis located between Kairouan and the Chott area. Sandstones are unknown eastward, in thePelagian Sea wich is also located on the northern edge of the Saharian shield. This disposition seems to be due to genral currents along the southern margin of the tethys. For that reason, thicknesses are less important eastward, where deposits are more calcareous, than westward where marls and sandstone were predominent in the series , except in a few places during late Valanginian-early Hauterivian (Dolomies Doouleb 101 Formation) and Aptian time characterized by huge calcareous deposits. This general disposition lead to the development of carbonate platform environments northward, in central Tunisia. Westward, near the Algerian-Tunisian boundary, the platform shelf edge turns to the south, then lies alongside of the Saharian shield in eastern Algeria from South of Kenchela to south of Batna. 1, location of sandstone beds toward the north (Late Berriasian-early Valanginian). 2, location of sandstone beds (Valanginian or Hauterivian ?). 3, Thick sandstone deposits of the Sidi Aïch Formation (at that time, thin sandstone beds are also known northward).

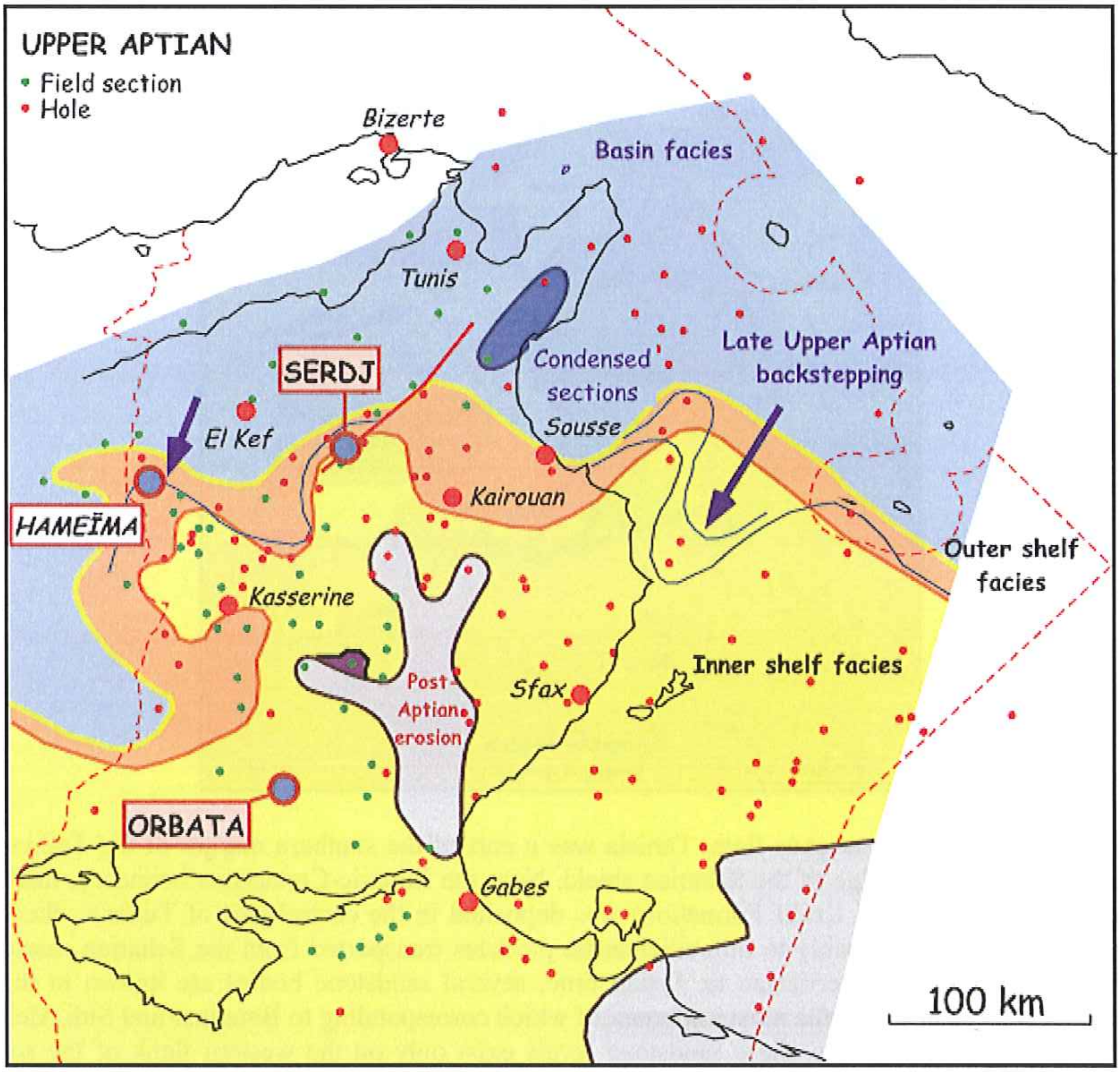

Fig.13.– Schematic paleogeographic map of Tunisia during late Aptian time. Late early Aptian and early late Aptian correspond to huge transgressive period. The Saharian shield is partly submerged. Aptian platform is characterized by progradation then backstepping. Thick deposits are known along the shelf margin (Serdj Formation is more than 1600 m thick in the type locality [Tlatli, 1983]. In the north-west area, diapirism occur probably in Djerissa (near Tadjerouine) and Ouenza (eastern Algeria, near Kalaat es Senam).

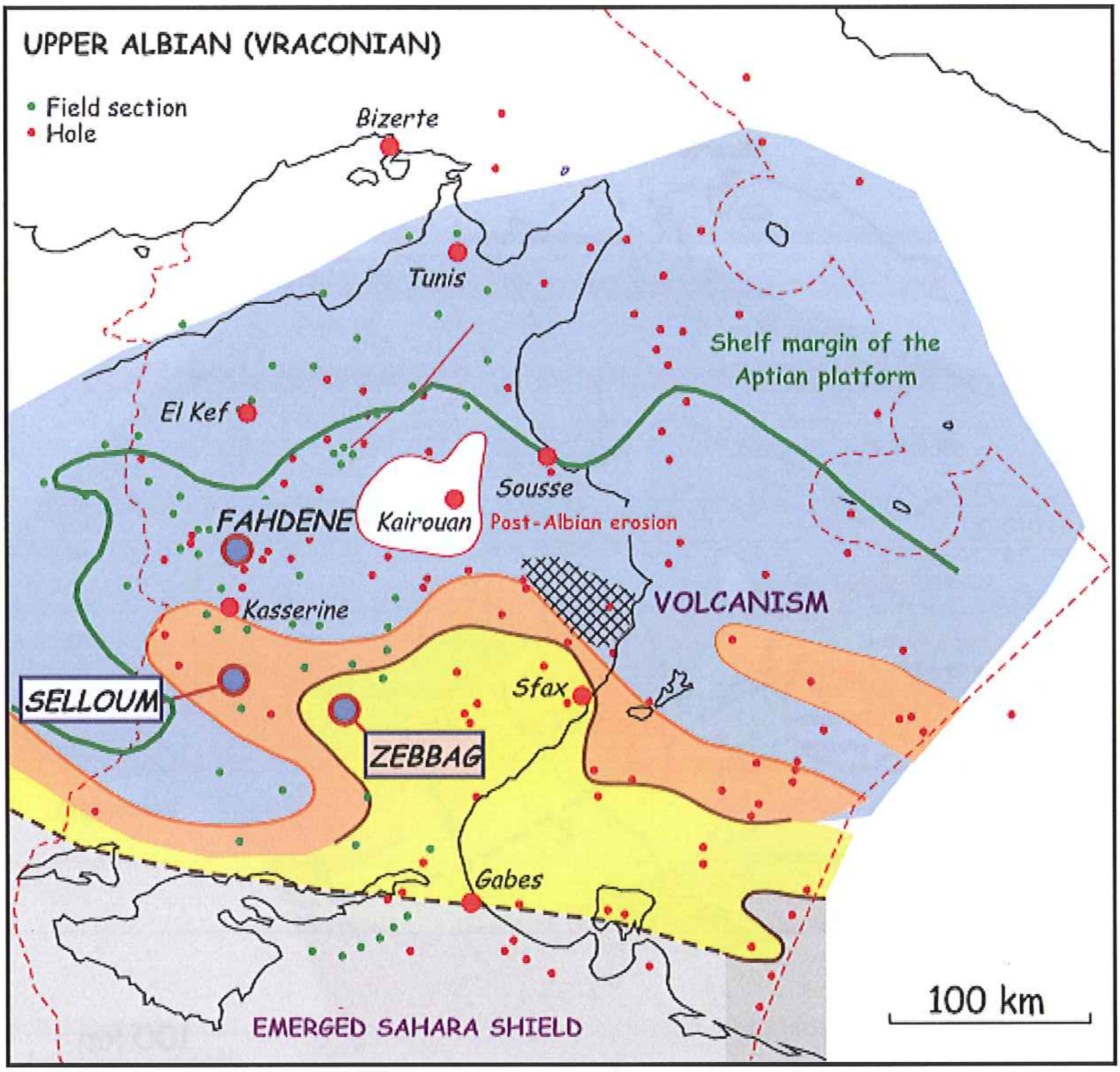

Fig. 14.– During Albian transgression, the old Aptian platform was drowned and earely to late albian deposits onlapped different levels of the Serdj calcareous Formation. Small-size subsident basins and emergent area appear during the Apto-Albian tectonic unstability : subsident area were infilled by thick early Albian deposits since emergent area are covered by younger middle to late Albian series. Toward the south, latest Albian (Vraconian) is represented by thick inner platform sedimentation which rests directly upon the late Aptian Orbata Formation. Vraconian volcanism is known in the Syrte area.

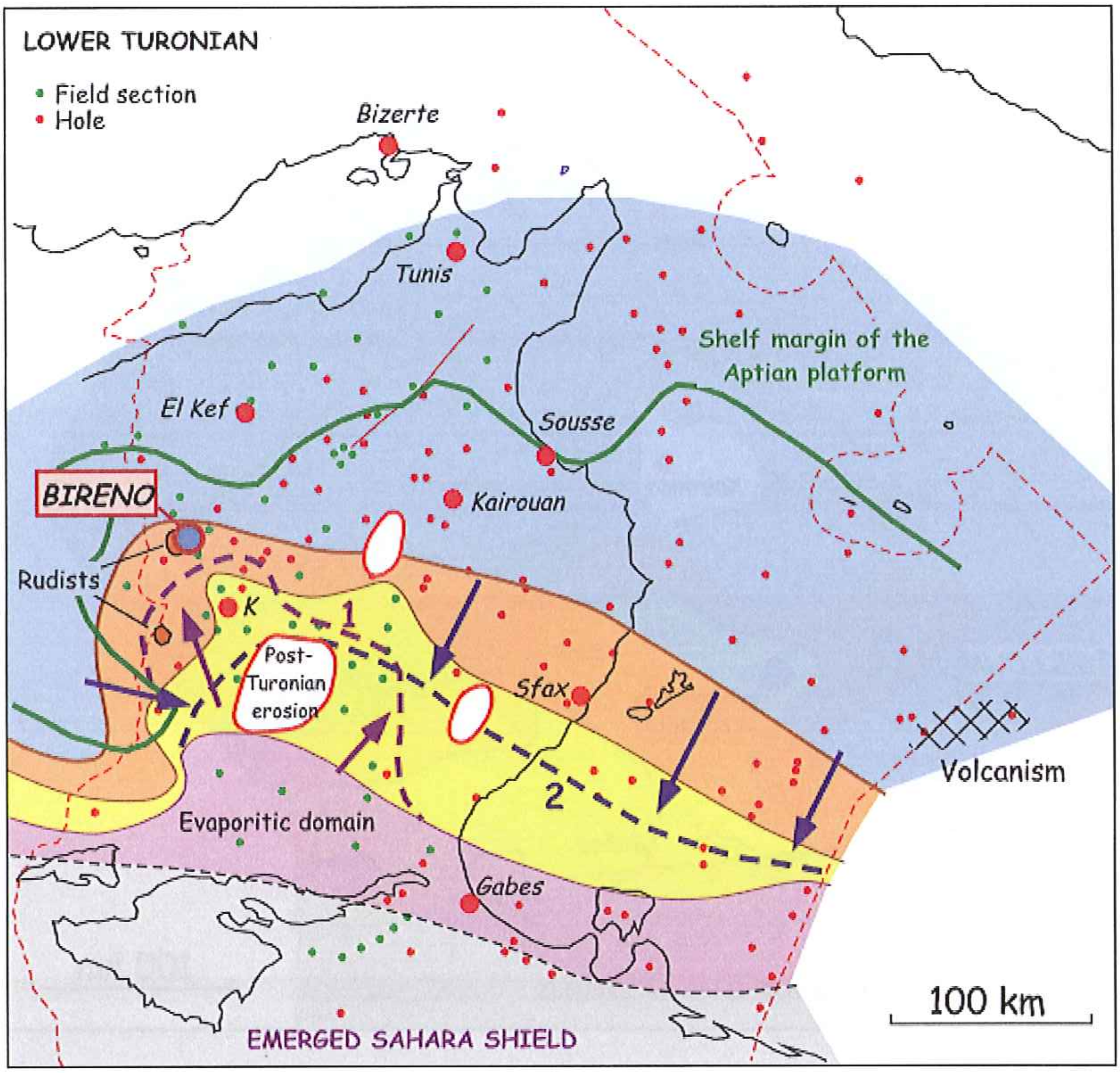

Fig. 15.– During early Turonian time, the general extension of the platform is similar to that of late Albian. The inner platform is characterized by development of evaporitic environments. Rudist communities exist in some points of the outer platform domain. The Gafsa area, north of the chott domain, show relatively thick subsident series, probably due to late Cenomanian to early Turonian tectonic unstability along the Gfsa fault. Volcanism occurs in the Syrte area. 1, Northern maximum extension of evaporitic facies. 2, Southern extension of relatively thick marls on the platform.

Paleontological data

Ma	Stage	Substage	NW EUROPEAN PROVINCE (Casey, 1961) (Latil, 1991) Zones	NW EUROPEAN PROVINCE Subzones	WEST MEDITERRANEAN PROVINCE (Hoedemaecher et al., 1993) (Latil, 1994, 2005) Zones	WEST MEDITERRANEAN PROVINCE Subzones	Regional zonation this work Zones and horizons
	CENOMANIAN	LOWER	*Mantelliceras mantelli*		*Mantelliceras mantelli*	*Mantelliceras saxbii* *Sharpeiceras schlueteri* *Neostlingoceras carcitanense*	
	ALBIAN	UPPER	*Stoliczkaia dispar*	*Stoliczkaia dispar* *Stoliczkaia blancheti*	*Stoliczkaia dispar*	*Arrhaphoceras (P.) briacensis* *Mortoniceras perinflatum* *Mortoniceras rostratum* *Mortoniceras fallax*	? *Mortoniceras rostratum* *Mortoniceras fallax*
100	ALBIAN	UPPER	*Mortoniceras inflatum*	*Callihoplites auritus*	*Mortoniceras inflatum*	*Mortoniceras inflatum*	*Mortoniceras inflatum*
	ALBIAN	UPPER	*Mortoniceras inflatum*	*Hysteroceras varicosum* *Hysteroceras orbignyi*	*Mortoniceras inflatum*	*Mortoniceras pricei*	*Mortoniceras pricei*
	ALBIAN	UPPER	*Mortoniceras inflatum*	*Dipoloceras cristatum*	*Mortoniceras inflatum*	*Dipoloceras cristatum*	?
	ALBIAN	MIDDLE	*Euhoplites lautus*		*Euhoplites lautus*		
	ALBIAN	MIDDLE	*Euhoplites loricatus*		*Euhoplites loricatus*		
105	ALBIAN	MIDDLE	*Hoplites dentatus*		*Hoplites dentatus*	*Hoplites spathi* *Lyelliceras lyelli*	
	ALBIAN	LOWER	*Douvilleiceras mammilatum*		*Douvilleiceras mammilatum*	*Lyelliceras pseudolyelli*	*Lyelliceras pseudolyelli*
110	ALBIAN	LOWER	*Leymeriella tardefurcata*	*Leymeriella regularis* *Leymeriella acuticostata*	*Leymeriella tardefurcata*	*Leymeriella regularis* *Leymeriella tardefurcata*	
	APTIAN	UPPER	*Hypacanthoplites jacobi*		*Hypacanthoplites jacobi*		
	APTIAN	UPPER	*Nolaniceras nolani*		*Nolaniceras nolani*		
115	APTIAN	UPPER	*Parahoplites melchioris*		*Parahoplites melchioris*		
	APTIAN	UPPER	*E. subnodosocostatum*		*E. subnodosocostatum*		
	APTIAN	LOWER	*Dufrenoyia furcata*		*Dufrenoyia furcata*		
	APTIAN	LOWER	*Deshayesites deshayesi*		*Deshayesites deshayesi*		
	APTIAN	LOWER	*Deshayesites weissi*		*Deshayesites weissi*		
120	APTIAN	LOWER	*Deshayesites tuarkyrus*		*Deshayesites tuarkyrus*		

Fig.1 – Ammonite zonation from NW European Province, W Meditteranean Province and Central Tunisia

PRELIMINARY DATAS ON THE LOWER ALBIAN AMMONITE SUCCESSION IN THE NORTH WEST OF TUNISIA AND ADJACENT AREAS OF ALGERIA: THE HAMEIMA SECTION

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Introduction

Our understanding of the Albian ammonite succession of North-East of Algeria and North-West of Tunisia was based on the works of Pervinquière (1903, 1907, 1910), Dubourdieu (1953, 1956), Dubourdieu and Sigal (1949), Sornay (1955). Dubourdieu (1956) provided a zonation based on acanthoplitinid ammonites and gave an Aptian age to the lower-middle part of acanthoplitinid beds, despite of the occurrence of the genera *Douvilleiceras* and *Platiknemiceras*.

More recently, Memmi (1999) attempted to correlate these successions with the ammonite zonal standard of Mediterranean area (Hoedemaker et al., 1993).

New and important ammonite collections made in 2004, north of Jebel Hameima, Tadjerouine area, have revealed the need of a revision of the ammonite faunas described by Dubourdieu, which were believed to be of Upper Aptian age. This revision will undoubtly help to clarify the age of the ammonite succession.

The Hameima section was sampled bed by bed and provided us hundreds of ammonites in LowerAlbian, and not a single one in Middle Albian.

The Acanthoplitinae succesion (HMA24-54).

In the lower part of the section, between first identified ammonite occurrence and last Acanthoplinid occurrence (HMA24-54), we collected almost exclusively Acanthoplitinae with scarce Engonoceratids, desmoceratids, heteromorphs and *Douvilleiceras*.

These Acanthoplitinae are herein doubtly placed in the genus *Neodeshayesites* Casey, as revised by Robert (2002) and Robert and Bulot (in Press).

Beds HMA24-27 are characterized by the occurrence of *Neodeshayesites paucicostatus* (Breistroffer) and *Neodeshayesites* sp. of the group of *N. ouenzaensis* (Breistroffer). The age of this interval remains unknown, Uppermost Aptian or more probably Lower Albian.

Beds HMA27-30 are characterized by the occurrence of a new *Neodeshayesites* fauna and the first occurrence of the genus *Douvilleiceras*. The undoubtfully occurrence of *Douvilleiceras leightonense* Casey in bed 28 clearly demonstrates a Lower Albian age just above *N. paucicostatus* beds. *Douvilleiceras leightonense* was reported from the *Leymeriella* *tardefurcata* zone to the Lower part of *Sonneratia (Sonneratia) chalensis* zone in the South-East of France (Kennedy et al. 2000) and Anglo-Paris Basin (Owen 1988).

HMA33-36 contains *Neodeshayesites* sp. of the group of *N. ouenzaensis* (Breistroffer). At the top of this interval occurs *Neodeshayesites* nov sp. (= *Sonneratia* (?) nov. sp. Breistroffer in Dubourdieu.

HMA38-47 is characterized by the occurrence of a new species of the genus *Neodeshayesites* homeomorph with *Hypacanthoplites*. Representants of the genus *Douvilleiceras* were collected in HMA 47.

The genus *Neodeshayesites* is very rare but still present in the interval HMA52-54 with very inflated morphologies.

The interval HMA24-27 can be correlated with the *Hypacanthoplites paucicostatus* zone of Dubourdieu (1956).

The interval HMA28-36 is equivalent of the *Hypacanthoplites trautscholdi* zone of Dubourdieu (1956).

The interval HMA38-54 corresponds very probably to the *Acanthoplites* gr. *seunesi*? zone of Dubourdieu (1956). The ammonite mentioned by Dubourdieu (1956) and determined as *Douvilleiceras* gr. *albense-monile* by E. Basse and C.W. Wright, was probably collected within this interval. *Douvilleiceras monile* was reported from top of *Sonneratia (S.) chalensis* zone and lower part of *Otohoplites auritiformis* zone in Anglo-paris basin (Owen 1988).

The Engonoceratidae succession.

Engonoceratids are very rare in the Hameima section: only two fragments have been found (HMA27 and 30) and could be reffered to the genera *Platiknemiceras* and *Parengonoceras*. In Algeria, first engonoceratids have been found South of Jebel Ouenza. They co-occur with *Neodeshayesites paucicostatus* and could belong to the genus *Platiknemiceras* Bataller.

The *Parengonoceras* faunas described in Dubourdieu (1953) from Jebel Bou-khadra, co-occur with *Douvilleiceras inaequinodum* (Quenstedt) and *Prolyelliceras flandrini* Dubourdieu, 1953).

It should be noted that *Knemiceras hachourii* Dubourdieu, 1953 was found in the same beds than *Parengonoceras mahoudi* (Dubourdieu, 1953) and *P. algerianum* (Dubourdieu, 1953) and could represent a morphological link between The genera *Platiknemiceras* and *Parengonoceras*.

The *Prolyelliceras* succession.

The genus *Prolyelliceras* Spath is represented in the Hameima section by two species : *Prolyelliceras flandrini* (Dubourdieu) and *P. radenaci* (Pervinquiere).

P. flandrini was found in the interval HMA57-68 and co-occurs with *Oxytropidoceras (Mirapelia)* aff. *advena* Kennedy in HMA57 and *Oxytropidoceras (Mirapelia)* aff. *mirapelianum* (d'Orbigny) in HMA67-68.

In Jebel Bou-Khadra (Algeria) *P. flandrini* and *Douvilleiceras inaequinodum* was collected from the same bed closed together with *Parengonoceras* ssp. *Douvilleiceras* *inaequinodum* is reported from the top of *Otohoplites auritiformis* zone in Anglo-paris Basin (Owen 1971, 1988).

P. radenaci, which is a probable offshoot of the former species, was found only in HMA74 among hundreds of desmoceratids. The interval HMA74-78 yielded limonitic ammonites, which fauna is largely dominated by desmoceratids. The most fossiliferous bed is by far HMA74. Then ammonites become very scarce and no ammonite was found above HMA78.

Conclusion

The three ammonite zones defined by Dubourdieu (1956) in Algeria can be recognized in the lower part of ammonite beds of the Hameima section. This zonation has yet to be revised and precised.

A taxonomical revision of the ammonite faunas is needed. It will be undertaken on the base of the historical material collected by Dubourdieu, and the important material collected by us in the Hameima section, and on the base of further investigations. It will undoubtly give rise to new paleontological and stratigraphical information.

More investigations are to be done and we expect to establish a regional zonal scheme based on ammonites that could permit long scale correlations with other south-Tethyan area and northern Tetyan margins.

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REMARKS ON AMMONITE ZONATION FOR THE UPPER AND MID-CRETACEOUS (IN PART) OF CENTRAL TUNISIA

F. Amedro

Upper Albian s.s. and Vraconnian.
Successive *Mortoniceras* zones are almost universally used because of the cosmopolite extension of index species. At the top of the Vraconian, the *Stoliczkaia (Shumarinaia) africana* zone (the type of the species created by Pervinquière, 1907 comes from central Tunisia) is used in the Tethysian realm in place of the *Arrhaphoceras (Praeschloenbachia) briacensis* zone, which is restricted to North-West Europe.

Cenomanian.
The ammonite zonation of basal Cenomanian is the most precise and best documented one in the south-tethysian realm, owing to a continuous sedimentary record on both sides of the Albian ("Vraconian")-Cenomanian boundary and to the occurrence of an abundant and well-preserved ammonite fauna. In the lower Cenomanian, earliest middle Cenomanian and upper Cenomanian, ammonite fauna are characteristically cosmopolite and allow the use of the standard zones defined in North-West Europe. Conversely, *Paraconlinoceras* aff. *barcusi* then *Acanthoceras amphibolum* zones of the uppermost middle Cenomanian were created in the Western Interior of the USA and reveal a momentary migration of fauna of north-American origin.

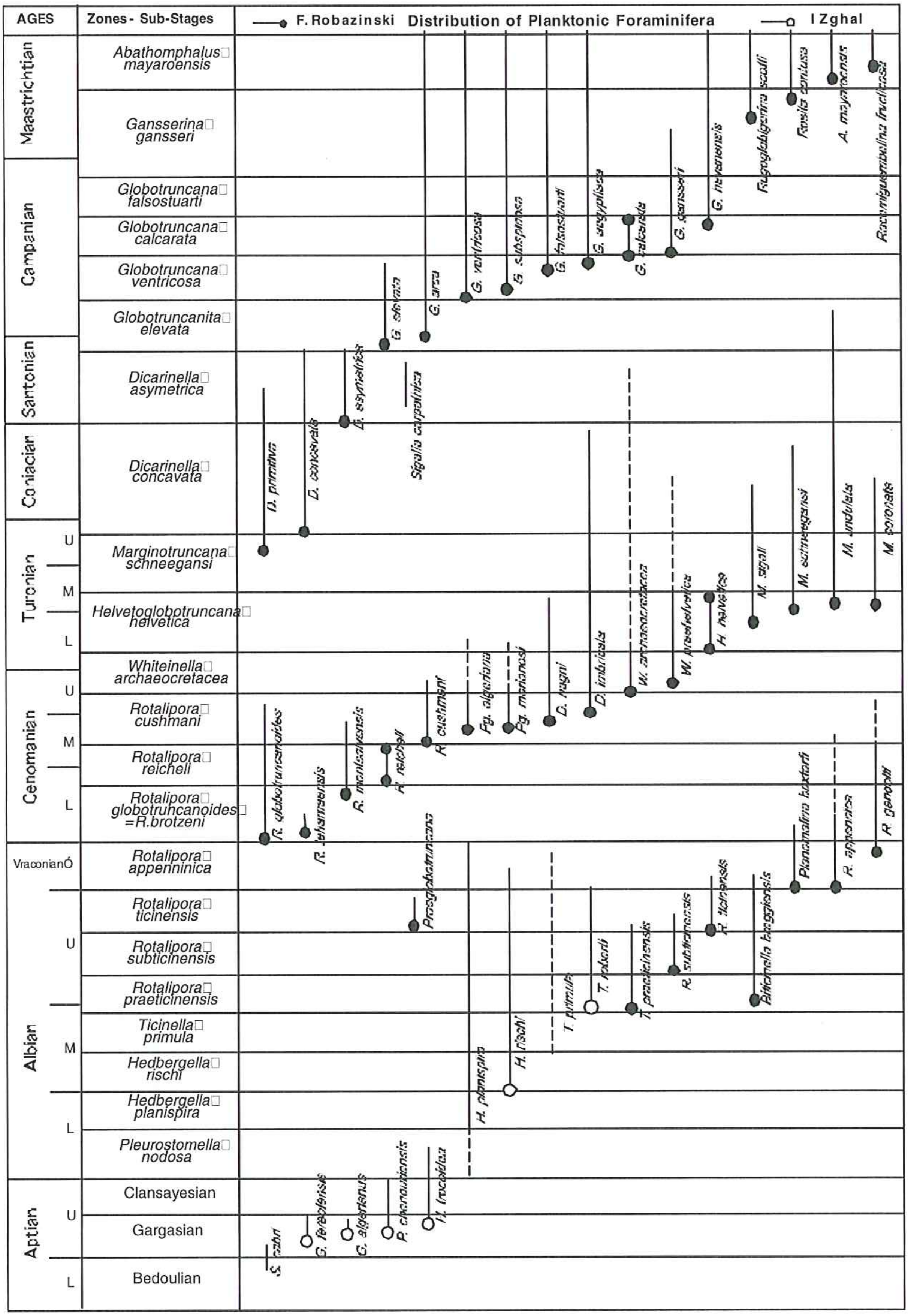
Turonian.
With eleven recognized biozones, Turonian ammonite zonation of central Tunisia is the most refined one in the Tethysian realm and one of the more precise in the world. The occurrence of mix-up fauna of boreal and Tethysian affinities is of great importance for correlation between faunal realms. Take note of the occurrence of several successive populations of *Prionocyclus* at the top of the upper Turonian as new north-American influences.

Coniacian to Maastrichtian.
Ammonites gathering is more discontinuous and provides fragmented information; nonetheless it is still very interesting. All in all, the recognized zones remain characteristically cosmopolite and allow large-scale correlations, together with North Europe, USA and Japan.

The table was realized by F. Amédro (01.12.2004) and is based on the following literature:
- AMEDRO (2002) for the upper Albian s.s. and the Vraconnian;
- ROBASZYNSKI *et al.* (1993); AMEDRO, ACCARIE & ROBASZYNSKI (submitted) for the Cenomanian;
- ROBASZYNSKI *et al.* (1990, 2000); CHANCELLOR *et al.* (1994) for the Turonian;
- ROBASZYNSKI *et al.* (2000) for the Coniacian, Santonian and Campanian;
- ROBASZYNSKI *et al.* (2000); GOOLAERTS *et al.* (2004) for the Maastrichtian.

Stages GTS 2004		Ammonite zones or intervals
65.5		
MAASTRICHTIAN		*Indoscaphites fauna (in pyrite)*
		Nostoceras (Nostoceras) alternatum
70.6		
CAMPANIAN		*Nostoceras (Nostoceras) hyatti*
		Nostoceras (Bostrychoceras) polyplocum
83.5		
SANTONIAN		
		Texanites interval
85.8		
CONIACIAN		*Protexanites* and *Paratexanites* interval
		Forresteria cf. *alluaudi*
		Buchiceras cf. *tunisiense*
		Barroisiceras cf. *tunetanum*
89.3		
TURONIAN	U	*Prionocyclus germari*
		Prionocyclus novimexicanus
		Prionocyclus sp. & *S. neptuni*
		Romaniceras deverianum
	M	*Coilopoceras* interval
		Romaniceras kallesi
		Kamerunoceras turoniense
	L	*Mammites nodosoides*
		Thomasites rollandi
		Pseudaspidoceras flexuosum
		Watinoceras sp.
93.5		
CENOMANIAN	U	*Pseudaspidoceras pseudonodosoides*
		Metoicoceras geslinianum
		Eucalycoceras pentagonum
	M	*Acanthoceras amphibolum*
		Paraconlinoceras aff. *barcusi*
		Acanthoceras cf. *rhotomagense*
		Cunningtoniceras inerme
	L	*Mantelliceras dixoni*
		Mantelliceras cf. *mantelli*
		Graysonites cobbani
		Graysonites azregensis
99.6		
VRACONNIAN		*Stoliczkaia (Shumarinaia) africana*
		Mortoniceras (Subschloenbachia) perinflatum
		Mortoniceras (Mortoniceras) fallax
UPPER ALBIAN		*Mortoniceras (Mortoniceras) inflatum*
		Mortoniceras (Mortoniceras) pricei

Distribution of planktonic foraminifera according to F. Robazinsky and I. Zghal



DAY 1 – JEBEL EL HAMRA - KASSERINE AREA

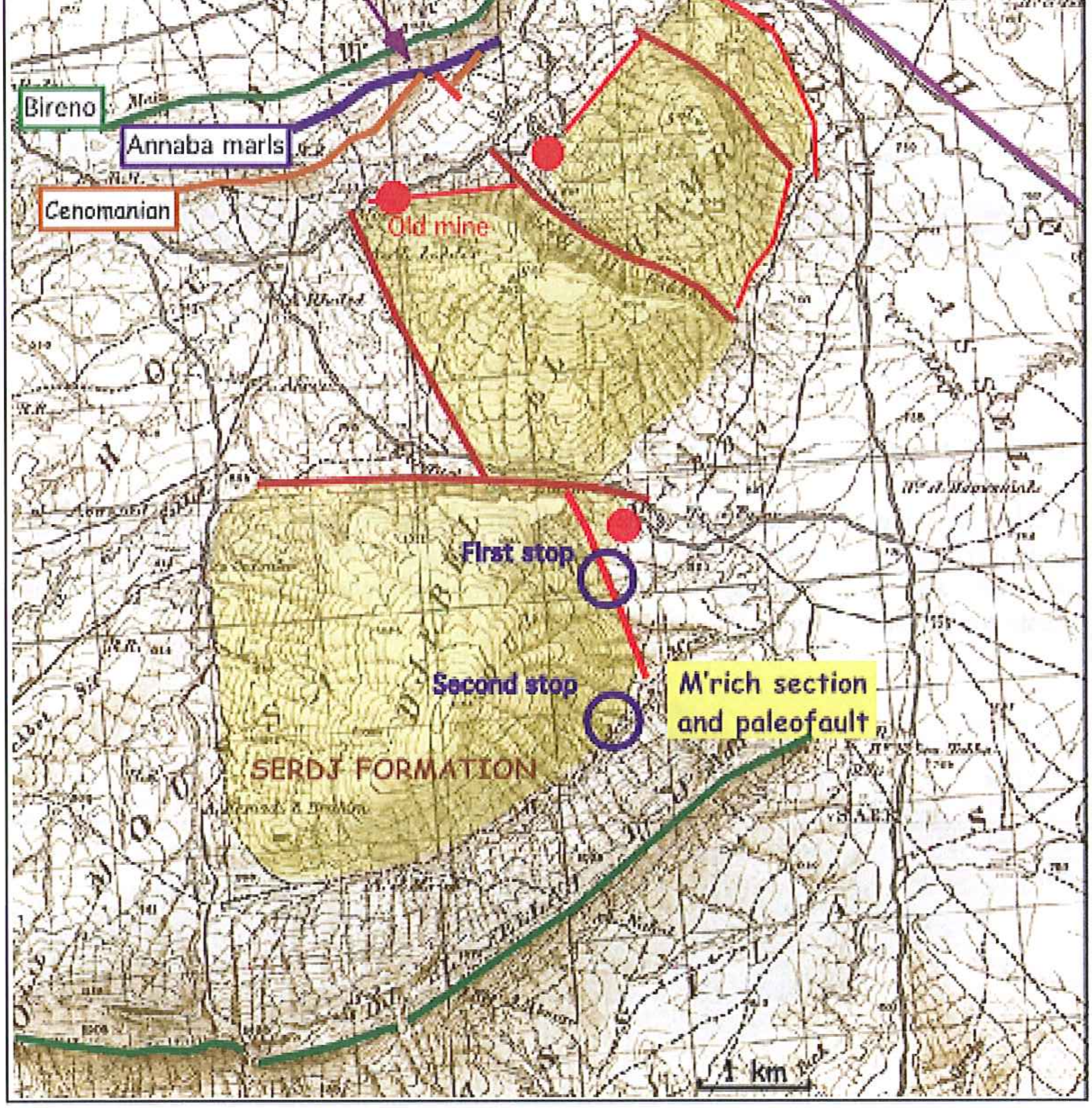


Fig.B1– Topographic map of the Djebel El Hamra, NW of Kaserine, showing the location of the stops.

GEOGRAPHIC AND TECTONIC SETTING OF JEBEL EL HAMRA

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The Jebel El Hamra is an asymetric anticline, NNE-SSW oriented, which is separated in three blocks by E-W to NW-SE, northward-dipping major normal faults.

Fig. 1 – General view from the East of the Jebel El Hamra

1 - Overall structure, compressional deformation

The Jebel is made of Aptian dolomites (Serdj fm, Upper Aptian), which are more steeply dipping on the eastern side. At its southern termination, the anticlinal axis is plungin southwards, and it is possible to observe the stratigraphic contact with the surrounding Fahdene formation (Albian).

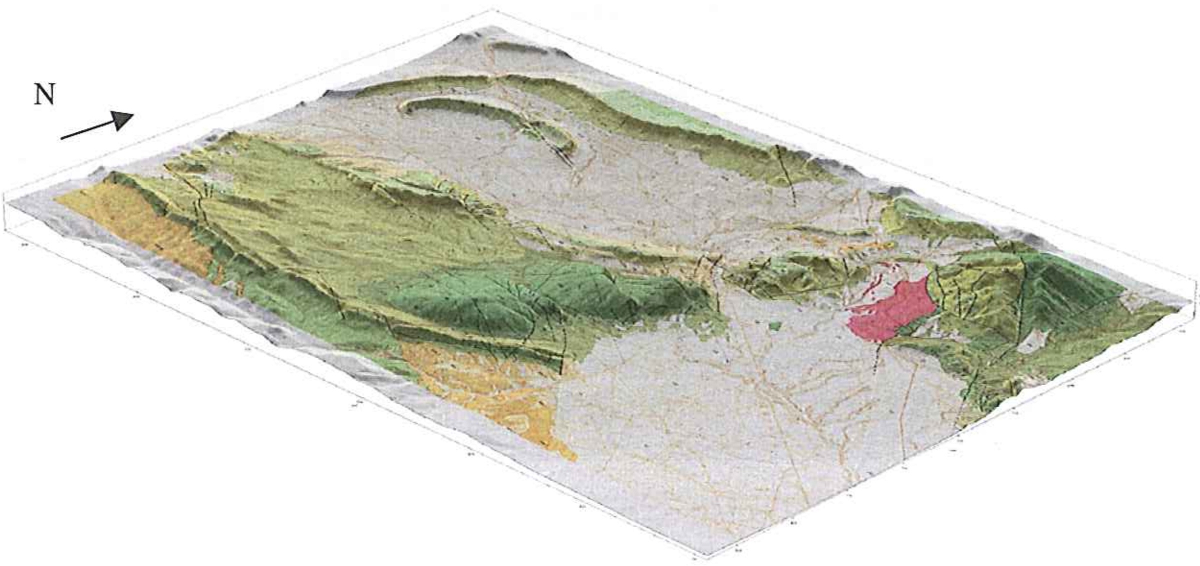

Fig. 2 - Geological map of Tunisia, drapped over SRTM (Nasa) Digital Elevation Model

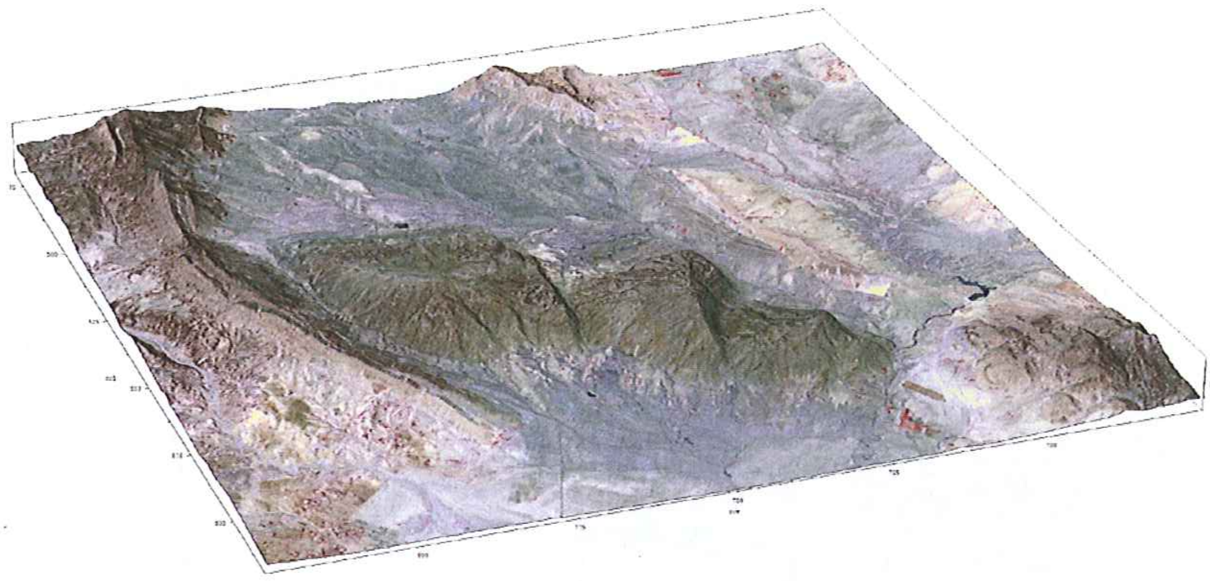

Fig. 3 - ASTER satellite image, drapped over SRTM Digital Elevation Model ; Data source : Nasa)

Fig. 4 - Southern periclinal termination (view from the South)

Fig.5 - Central part of the jebel, asymetric anticline (view from the south)

Microstructural data clearly document this anticlinal structure with southern periclinal termination (see below). Some evidence of reverse faulting towards the E or SSE are found at the bottom of the eastern lim of the anticline, which can be regarded as a E-directed fault propagation fold. However, these brittle compressional features less affect the southern termination of the jebel, and the stratigraphic contact between the Serdj and Fahdene formations is better preserved.

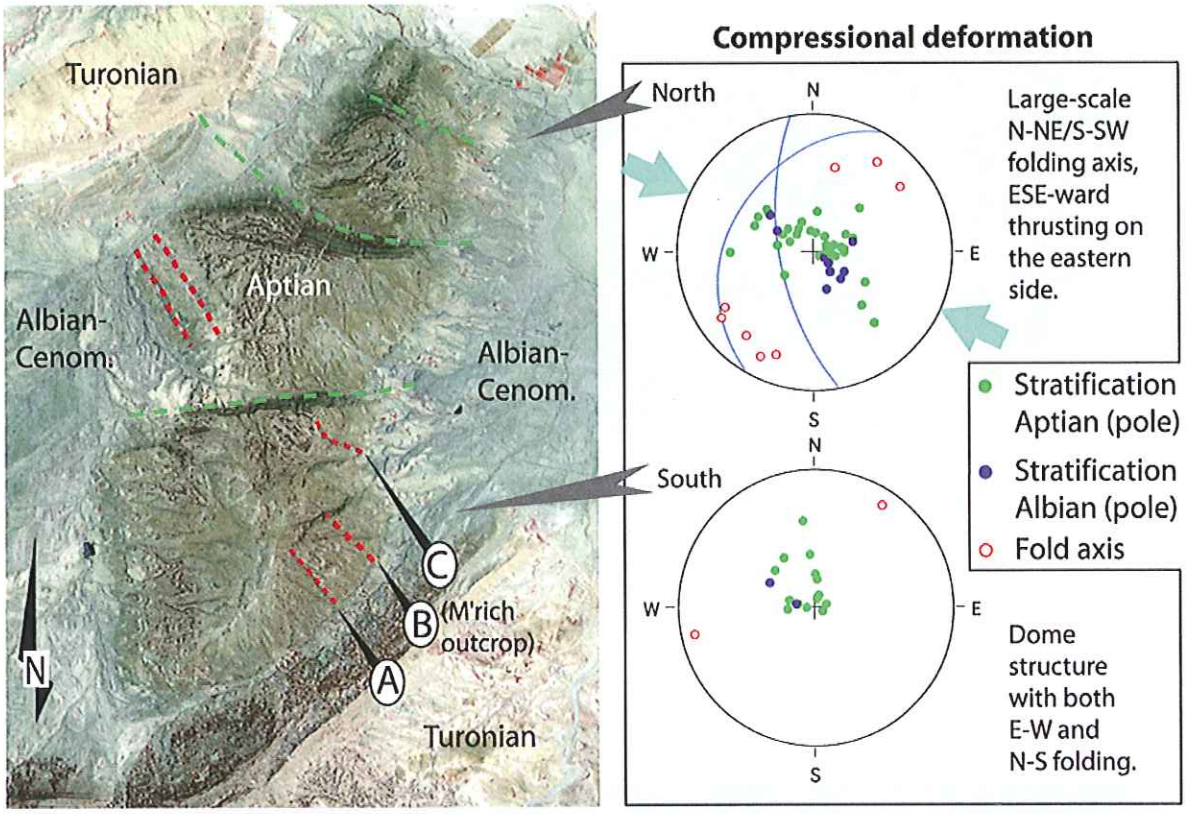

Fig.6 – Results of microstructural analyses concerning the compressional deformation.

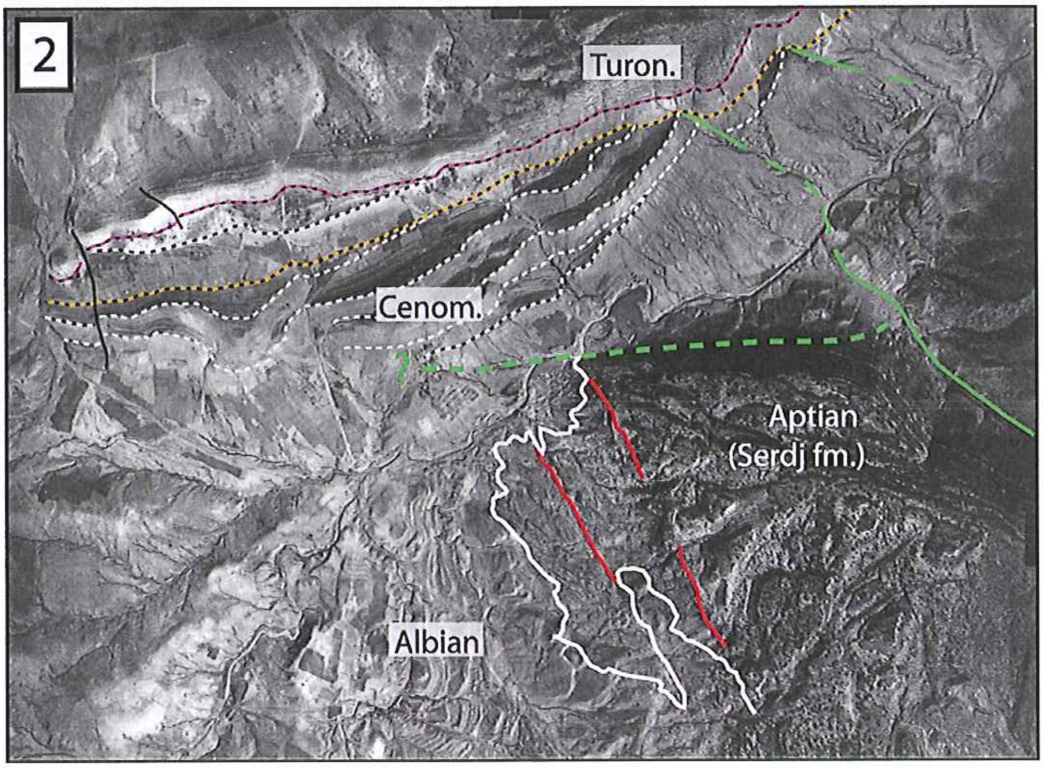

Fig.7 - Cretaceous faults on the NW side of the Jebel El Hamra, aerial photograph.
Red: Aptian faults ; green: Albian to Cenomanian faults ; white: top of Serdj fm.

This contact is affected by small-scale, NNW-SSE oriented normal faults whose decametric offset can be accurately dated as will be shown in stop 2 (M'Rich outcrop, point B, Fig. 6). This small-scale, Aptian fault pattern (red dotted lines, above) is of course involved in anticlinal folding, which must be younger than Turonian according the litterature (Soyer & Tricart, 1989 ; Bouaziz et al., 2002 ; Patriat et al., 2003). The major, E-W to NW-SE normal faults (green dotted lines, above) probably also predate anticlinal folding since aerial and satellite images show that one of them is sealed by the Turonian Bireno formation.

2- Cretaceous extensional deformation

A pattern of small-scale, NNW-SSE oriented normal faults is found in the southern and western parts of the jebel. The associated tilted blocks are sealed by the Fahdene formation (blue dotted line, below).

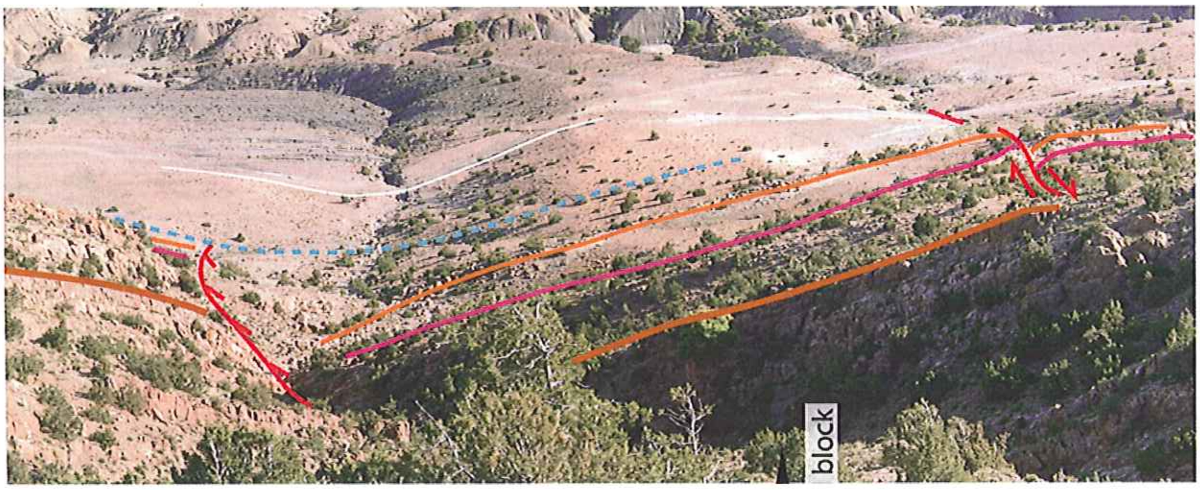

Fig.8 - (M'rich outcrop, view towards SE)

Once restored by unfolding the anticlinal structure, these faults were oriented N140° to N150° in Cretaceous time, and blocks were tilted NE-wards (see fig. 9).
Sequence stratigraphic and biostratigraphic analysis demonstrate that the breakup of the Serdj formation and the final sealing of the blocks occurred in Upper Aptian and Albian time, respectively. A condensed sequence with Early Albian fauna is found at the bottom of the half-graben.

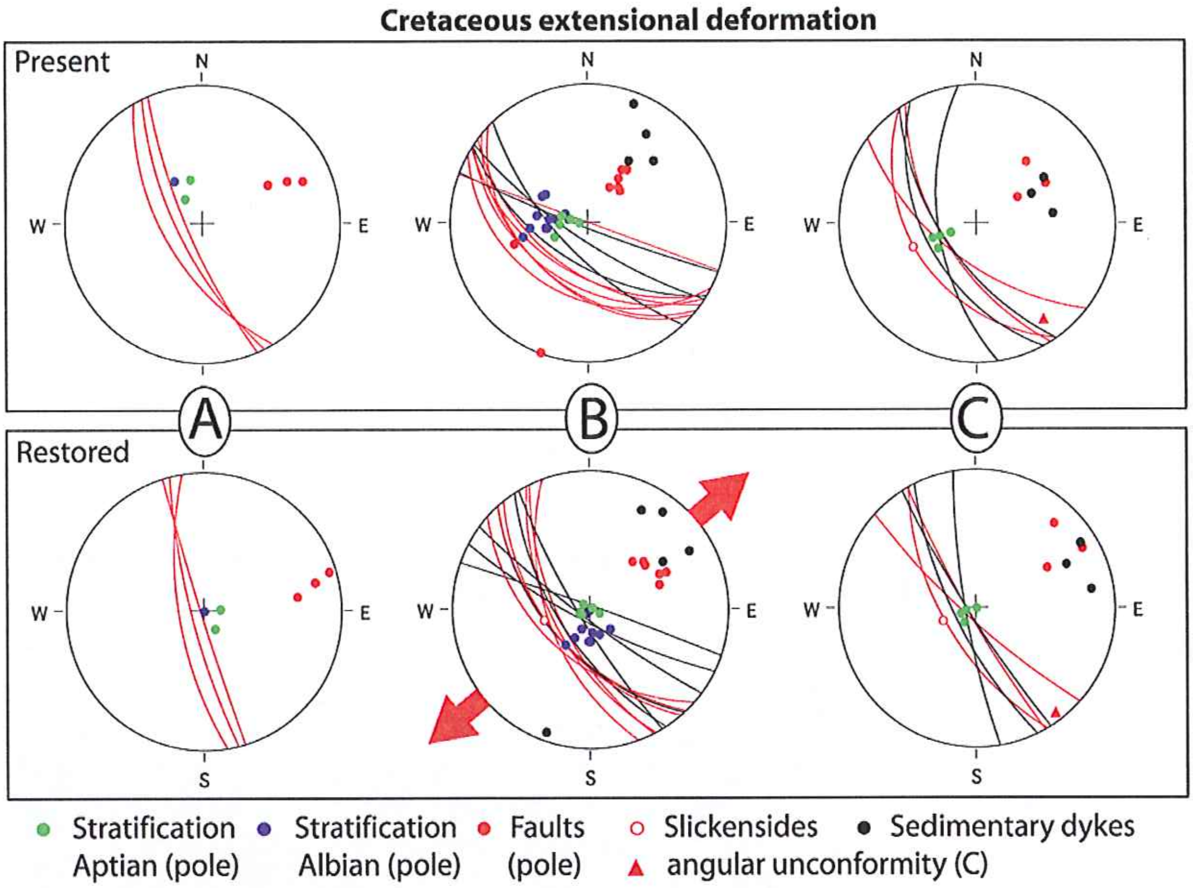

Fig.9 Microstructural analyses showing Cretaceous extensional deformation

The more recent extensional fault pattern (green dotted lines, Fig. 7), which is associated with angular unconformities within the Albian and Cenomanian formations and is sealed by the Turonian Bireno formation (aerial photograph, above) could be linked with the final emplacement of the Ajred diapir located to the NE of the jebel El Hamra. This could explain their curved shape, kilometric spacing (ring faults), and the erosion of Cenomanian beds below the Bireno fm. may be due to doming in early stages of diapir emplacement.

THE SERJ FORMATION OF THE JEBEL EL HAMRA

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The Serdj Formation is well exposed at the Jebel el Hamra with a total thickness of approximately 250 to 300 m. It consists of a succession of massive carbonate beds (dolomite and limestone) and less massive and generally covered by vegetation marls or argillaceous limestone. Five main levels can be recognized and numbered from 1 to 5. The base of the carbonate succession of Serdj formation is particulary well visible on the Fedj el Fakhat (fig.1).

Fig.1– Fedj el Fakhat outcrop showing the basal part of the Serdj Formation.

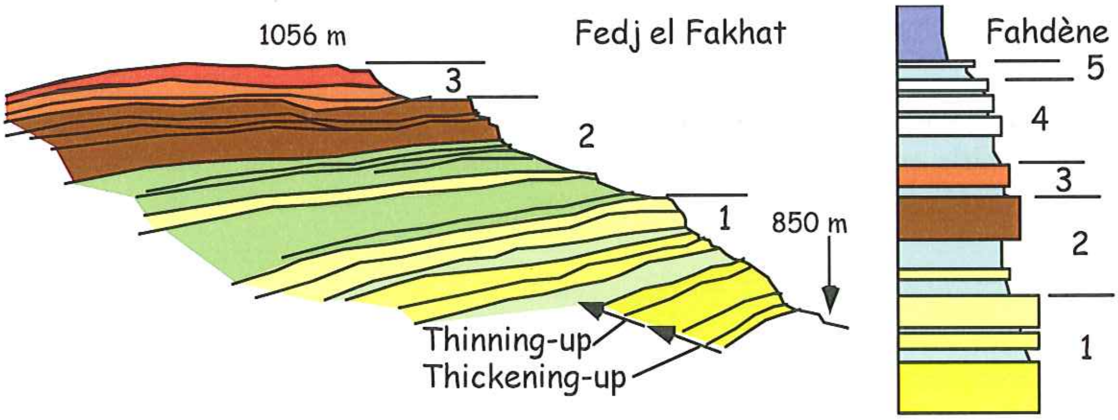

Fig.2– Skech of Fedj el Fakhat (Djebel el Hamra) showing the basal section of the Serdj fm. and the location of the five levels.

The cliff of Jebel El Fakkat shows from the bottom to top

1. The 1st level corresponding to the 80-90 m thick basal cliff consist of
   i) thick carbonate bed that are thickening-up, then thinning-up
   ii) more soft collection of probably marls or argillaceous limestones. Two thick carbonate sequences occur in the middle part.
   iii) thick and massive carbonate beds at the top.
2. The 2nd level (80-90 m) is made of thick marls and argillaceous limestone, which pass upward to thick carbonate sequences.
3. The 3rd level (approximately 30 m thick) corresponds generally to the top of the Djebel el Hamra plateau It is represented by argillaceous limestones and ends up with a thick carbonate sequence.
4. The 4th level consists of three (or four) relatively thin dolomitised limestone cliffs separated by more argillaceous beds (marly intercalations are sometime present). Oysters are frequent in some levels while corals occur in the last sequence below the disconformity D3 capping up the top of the cliff (see following text).
5. The 5th level is visible on the eastern flank of the Jebel el Hamra. This last sequence of the Serdj Formation is easy to recognize. From the bottom to the top it is made of argillaceous limestone beds rich on large oysters, black marls interbedded of yellow argillaceous limestone and a thick, massive dolomitised bed. The top of this bed corresponds to disconformity D4, which is a subaerial exposure surface. Albian marls overly the Serdj formation.

On the map fig.3, we see outcrops only visible on the South-West side of Jebel. They are interbedded between Serdj and Fahdene Formations and seem unknow in other sides of the Jebel El Hamra.

This section has not been studied in detail and only the last three cycles which constitute the 4th and 5th level have been measured and detailed on the eastern flank of the Jebel el Hamra (see Oued el M'rich section).

In 1981, Mrabet proposed to recognize a parastratotype of Serdj fm. in the Jebel El Hamra. But the proposed section represent only the upper half part of the Serdj formation.

Reference

M'rabet, A., 1981, Stratigraphie, sédimentation et diagénèse carbonatée des séries du Crétacé inférieur de Tunisie centrale: Docteur ès-sciences thesis, Université de Paris-Sud, centre d'Orsay, Orsay, 1-540 p.

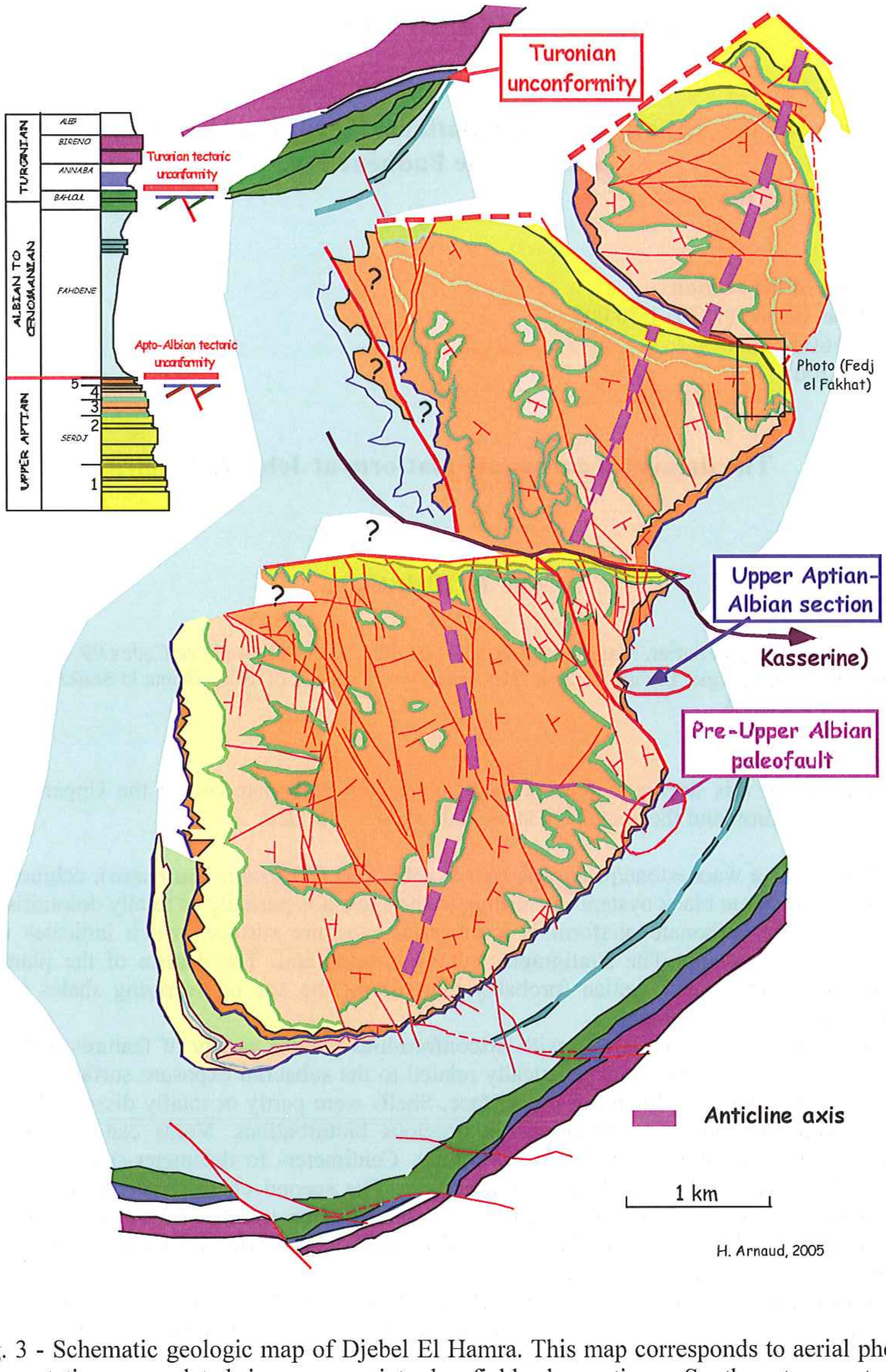

Fig. 3 - Schematic geologic map of Djebel El Hamra. This map corresponds to aerial photos interpretation, completed in some points by field observations. Southwestern outcrops between Serdj and Fahdene Formations seem to be unknown in other sides of the Jebel El Hamra.

STOP 1: EAST JEBEL EL HAMRA

Demise of the Aptian carbonate platform (Serdj Fm.) and Upper Albian marls of the Fadhène Fm.

Location of the section
Map Jebel Bireno (1930) 1/50 000
X = 370 600
Y = 230 200

The demise of carbonate platform at Jebel El Hamra

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The purpose of this stop is to present in detail the last carbonate bed of the Upper Aptian carbonate platform and the associated subaerial exposure surface.

The last bed is a wackestone/packstone rich in orbitolina (*Mesorbitolina parva*), echinoderm fragments and large black oysters. According to the sites, it is partially or totally dolomitised.
The top of the carbonate platform is a subaerial exposure surface, which indicates non-deposition and erosion. The stratigraphic hiatus is important. The demise of the platform occurs during the Upper Aptian (probably Gargasian); the age of overlying shales of the Fadhène fm. is Upper Albian.
Sedimentary structures associated with disconformities yield a variety of features reflecting weathering processes. Features genetically related to the subaerial exposure surface are both superficial and developed beneath the surface. Shells were partly or totally dissolved on the surface and solution voids developed in previous bioturbations. Voids can be fill with orbitolina-rich packstone or yellowish dolomite. Centimeter- to decimeter-sized voids are present in the last decimeter beneath the surface. The second characteristic feature is the occurrence of decimeter to meter sized karsts established on tectonic fractures, resulting in deeply karstified beds. Karst voids were filled by orbitolina-bearing packstone, and then by yellowish dolomite and terra rossa.
A detailed study of small microcaves and their sediment fills shows a complex succession of deposition and erosional surfaces related to sea-level oscillations and regression/transgression episodes between Upper Aptian and Upper Albian times.

We can identify the following stages.

1 - 1st Stage of dissolution responsible for superficial dissolution of shells, bioturbations and enlargement of fractures.
Age: Upper Aptian (probably Gargasian)

2 - 1st stage of transgression. The sediment fill is composed of reworked orbitolina and other bioclasts, which are worn and micritised.
Age: Upper Aptian (probably Gargasian)

3 - 2nd stage of emersion and dissolution. Microcaves were probably enlarged at that time and vegetation possibly covered the surface, since small size root molds are observed.
Age: Upper Aptian (probably Gargasian)

4 - 2nd stage of transgression. New voids and possible root molds are filled with a grainstone/packstone containing some phosphatic elements and sciaphile fauna (echinoderm and bryozoan fragments, small benthic foraminifera - Marssonella and nodosariids, planktonic forminifera – Favusella). Millimeter-sized rounded extraclasts can be observed. The presence of micritic pebbles with sponge spicules evidences that hemipelagic muds were previously deposited, lithified and eroded.
Age: Upper Aptian (probable Gargasian).

5 - 3rd stage of emergence and formation of new small cavities.

6 - 3rd stage of transgression. Cavities are filled with packstone containing Orbitolina (*Mesorbitolina parva*), exhibiting an agglutinated test made of abundant quartz grains.
Age: Upper Aptian.

7 - 4th stage of emergence and occurrence of new small karstic cavities. Green marls injected between grains present a brown color related to diagenetic alteration.

8 - 4th stage of transgression. A phosphatic layer coates cavern walls, and contains planktonic foraminifera.

9 - 5th stage of emergence and creation of new fractures.

10 - 5th stage of transgression. Cavities are filled with pelagic mudstone containing small sized planktonic foraminifera.

11 - 6th stage of emergence. This emersion is associated with dolomitisation of the void infill. Dolomite is very rich in iron oxydes and an ankeritic dolomite is developed, which contains small angular phosphatized fragments, broken bioclasts and glauconitic grains.

12 - 6th stage of transgression. The residual voids are filled by large rounded extraclasts (fragments of platform carbonates), by rounded phosphatic clasts, a few planktonic foraminifers, and quartz and glauconitic grains. Clasts are cemented by a new dolomite, which is less rich in iron.

There are no dating evidences for these last stages. However, phosphatisation probably occurred during the Lower Albian (cf. M'rich section).

Upper Albian section of Jebel El Hamra

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Location of the section

Map Jebel Bireno (1930) 1/50 000
X = 370 600
Y = 230 200

Preliminary sedimentologic and biostratigraphic data

The Upper Albian marls and shales of the Fadhene Fm disconformably overlies the carbonate platform of Serdj Fm.
Three ammonites zones of the Upper Albian has been identified: *Mortoniceras princei* zone, *Mortoniceras inflatum* zone and *Stoliczkaia dispar* zone *Mortoniceras (M.)* subzone. But the earliest Upper Albian is missing.
During the field trip, we will examine the two first Depositional Sequences of Upper Albian..
□

Fig.1 – General view of the Albian section

First Depositional Sequence (H16-H51) (Fig.2)

The first sequence (about 34m) is mostly represented by marls and shales. The sequence begins with alternation of decimeter to meter black to brown marl and decimeter bed of argillaceous limestone. These limestone may contain reworking elements coming from platform (Orbitolina, echinoderm and mollusk fragments), and are rich in belemnites and

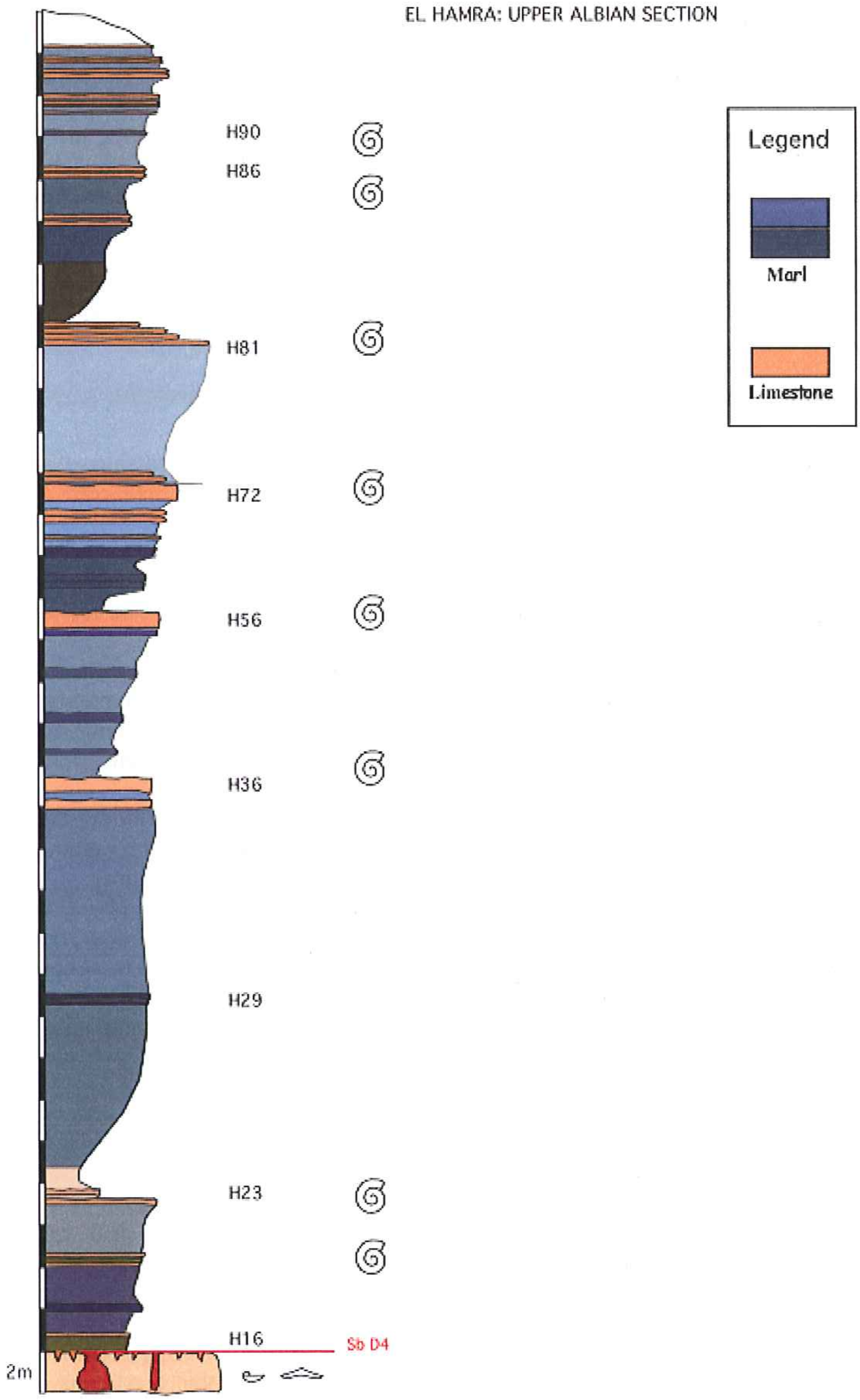

Fig.2 – Section of Albian marls of Jebel El Hamra

crinoids (bed H23). Ammonites are common in some beds (H15 –H25) and specimens of Mortoniceras (Deiradoceras) from *Mortoniceras princei* zone are frequent.
Marl-limestone alternation grade upward into black shales well exposed at the bottom and on the eastern flank of the gully. This interval is interpreted as the fining and deepening upward Transgressive Systems Tract and the black shales should be deposited during the Maximum Flooding period (between H28 and H29). Presence of lag at the base of the Transgressive Systems Tract is attested by reworked grains present in the more calcareous beds. The Highstand Systems Tract. displays black and blue shales which grade upward to argillaceous carbonate-marl alternation containing scarce ammonites.
The sequence boundary can be located at the bed H52, below the massive bed H56. This position is due to the fact that stable isotope analyses show a strong shift of □ C^{13} and □ O^{18} s below this bed and the occurrence of abundant calcispheres.

Second Depositional Sequence (H52-H95) (Fig. 2)

The second sequence (about 30m) begins with an aggrading succession of marl and argillaceous limestone passing upward from blue to yellowish or light brown color for the last carbonate beds
The decimeter carbonate bed H72 is capped up by a firm ground showing millimeter size bioturbations. These bioturbations affect the last centimeter of the bed and are filled by abundant calcispheres. Above this surface, marl-carbonate alternation grade rapidly upward into marls and black shales.
Ammonites present in this interval (H64 to H80) belongs to *Mortoniceras princei* zone with specimens of Mortoniceras sp.and *Histeroceras carinatum.* This interval is interpreted as the Lowstand Systems Tract or Shelf Margin Wedge and the Transgressive Systems Tract of this Depositional Sequence. The firm ground of the bed H72 can be interpreted as the Transgressive Surface.
The Maximum flooding period corresponds to the black shales exhibing oil-seeps (H83-H84) which are well exposed at the bottom of the gully. Planktonic tests of foraminifera are filled by asphalt. The bed H82 marks the transition between the two ammonites zones.
Above, the Highstand Systems Tract. grades upward from black and blue shales to carbonate-marl alternation. Ammonites from H 86 to H95 belong to *Mortoniceras inflatum* zone
The sequence boundary can be located below the bed H96 and corresponds to an abrupt facies change, the occurrence of radiolaria in significant number and a new shift of □ C^{13}. Brachiopods are present in the bed H96. Above the sequence boundary, ammonites found in the interval H96-H02 belongs to *Stoliczkaia dispar* zone, *Mortoniceras (M.)* subzone.

Paleoenvironment

Upper Albian marls and shales are pelagic deposit in very quiet environment.
The fauna consits of ammonites, planktonic foraminifera, radiolaria and calcispheres. Calcispheres are very abundant in Transgressive Systems Tract and their abundance can be linked to nutrient input. Ammonites are always present in Transgressive Systems Tract.
Maximum flooding period corresponds to the maximum abundance of planktonic foraminifera and presence of black shales rich in organic matter and very poor in carbonate. The two black shale intervals show evidence of periods of anaerobic conditions on the sea floor.
On top of Highstand System Tract, calcipheres and planktonic are less abundant. Planktonic echinoderms (Roveacrinidals) occur with brachiopods and belemnites

The rapid rise of sea-level at the base of the first Depositional Sequence displays lag made of reworked fragments of platform organisms. It also the time of occurrence of environments which are at the advantage of crinoids and belemnites.

STOP 2: EAST JEBEL EL HAMRA – M'RICH AREA

Location of the section
Map Jebel Bireno (1930) 1/50 000
X = 370 600
Y = 229 100

The three last Upper Aptian cycles of the Serdj Formation

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Fig.1 – View of the last Upper Aptian cycles of the Serdj Fm

The uppermost platform carbonates of the Serdj Fm. are well exposed south of a small paleofault (Fig.1).

There, three upward shoaling sedimentary cycles are bounded by unconformities called D1, D2, D3 and D4, respectively. Each cycle is bounded by unconformities, which are usually exposure surfaces with superficial karsts (Fig.2).

1 – The first cycle begins above the unconformity D1. The basal 5 m thick thin-bedded argillaceous limestones and marls are not well exposed, and are overlain by blue-green marls. The sequence D1 ends up with a small cliff made of a 11 m thick set of massive brown limestone beds, which are mostly dolomitised.

The unconformity D2 is a subaerial exposure surface. Green marls fill small superficial karstic cavities within the underlying limestone bed. The following transgression is marked by borings made by bivalves.

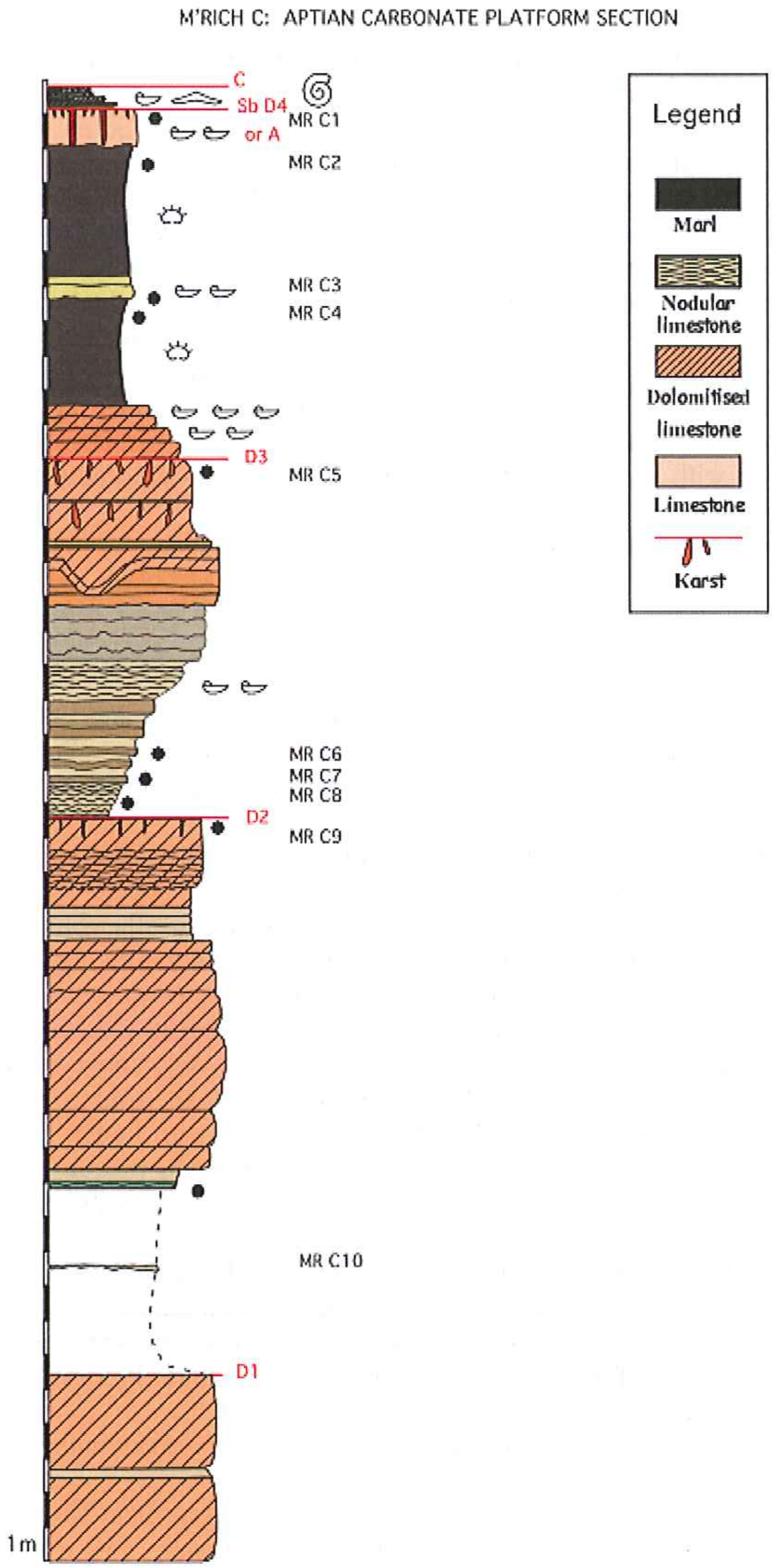

Fig.2 – M'rich section showing the position of unconformities D1 to D4

2 – The second cycle starts with a marly level grading upward into nodular beds, which contains less and less clay. The overlying cliff is composed of more massive dolomitised limestone beds. In its lower part, a channel evidences that tidal currents were active on the

platform, while some rudists and a few corals are present at the top.
The unconformity D3 is very important and occurs on a new paleotopography generated by tectonic activity. Tilted blocks were created at that time (Dumont et al., this volume) The emergent new topography is partly eroded and karstic cavities are formed. We can follow the D3 surface and observe the erosion surface and karstification. Some karstic cavities are superficial, but others are deeper and located on fractures enlarged by dissolution. These voids are covered by a thin mineralized layer and filled either by reworked orbitolina or yellowish dolomite. In the upper part of tilted blocks, voids are filled up by angular clasts derived from the underlying platform. The following transgression is also marked by a bored surface.
3 – The third cycle begins with two to four brown dolomitised beds rich in large black oysters, overlain by black marls devoid of microfauna, containing large black oysters and irregular echinoids. One or two yellow argillaceous limestone beds rich in orbitolina are interbedded within the black marls. The black marl varies laterally in thickness and may disappear on top of tilted blocks.
The cycle ends up with a meter thick bed of yellowish, partly dolomitised limestone rich in Orbitolina (*Mesorbitolina*).
The unconformity D4 displays the same types of karstification, as those observed at the previous stop.

Paleo-environments and interpretation of cycles

Faunal content of these deposits (echinoids, bryozoans, rudists and corals) indicate open circulation and normal marine salinity. The presence of orbitolina is indicative of detrital and nutrient input. The abundance of orbitolina is inversely proportional to that of rudists and corals.
At the base of cycles, the first decimeter of argillaceous and irregular beds are composed or reworked and rounded clasts (lag).
The deepest part of the cycles is represented by marls and argillaceous limestones, which contain sciaphile fauna (living below the photic zone): echinoderms, bryozoans and deeper marine foraminifera (Marssonella, nodosariids), and present wackestone or fine-grained grainstone textures. This deepest environment is usually closer to the base than to the top of the cycle. The deepest environment of cycle 2 occurs immediately above the surface D2.
The top of each cycle is made of a decimeter to meter thick limestone bed, partially or completely dolomitised when located close to fractures and faults. The base of these limestones presents festoon cross-beddings or erosional channels (sequence 1 and 2). On top of sequence 3, the limestone is always a packstone/wackestone with orbitolina and black oysters.
The D2, D3 and D4 unconformity correspond to subaerial exposure surfaces. The exposure surface D2 displays small size superficial karst filled by green marls.
The exposure surface D3 is more complex and shows superficial karst and karst developed along fractures. Sediment fill is also more complex with orbitolina or yellowish dolomite resting locally on a mineralized surface.
The exposure surface D4 is the most complex surface as can be seen on the previous outcrop.

Cycle after cycle, we note the increasing complexity in the sediment filling of karstic voids. Unconformity D2 probably corresponds to a short time exposure with a simple fill of green marl.
Unconformity D3 displays cavities containing 4 distinct deposits : mineralized layer, yellowish dolomite, angular clasts, and reworked orbitolina. Such a polyphased filling and diagenetic history suggests a long subaerial exposure.
Unconformity D4 is the most complex subaerial exposure surface. Sediment fill records various eustatic cycles and many subaerial exposure periods. The stratigraphic hiatus is most

probably important, as suggested by the rest of Upper Albian shales directly on the Upper Aptian carbonates.

Therefore, the duration of subaerial exposure seems to increase progressively with time and the upper surface of the uppermost limestone bed of the Serdj Fm. appears to encompass the longest hiatus.

Although these upward shoaling cycles are similar to parasequences, their significance in term of sequence stratigraphy is not yet clear. The duration of the subaerial exposure periods and of the correlative stratigraphic gaps appears too short to consider them as sequence boundaries. Unconformity D4, however, is a good candidate for a sequence boundary, since it marks the demise of carbonate platform, sediment filling caves registered various sea level oscillations, and the corresponding stratigraphic gap is probably important.

Sedimentation and tectonic setting between D4 unconformity and the base of the Upper Albian marls (bed 23)

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Bed 23 is a noticeable bed rich in echinoderms fragments, crinoids and belemnites.
Farther north (previous stop), this bed is geometrically very close to surface D4 (= A, see Jaillard *et al.* this volume), whereas it is separated from surface D4 by a thicker succession in the M'Rich area.

The previously described uppermost carbonate bed is overlain by a one meter thick layer of argillaceous limestone and conglomerate, which was missing at stop 1.

A more complete sucession is exposed south of the small paleofault.
There, the same meter thick layer of limestone and conglomerate, is overlain by 16 m of marls, shales and argillaceous limestones. (Fig.1-2)

The very base of the series is complex and can be described as follows.

1 – a 25 cm thick limestone bed contains reworked extraclasts of two origins :

i) worn and micritised orbitolina and rounded clasts of platform carbonates,

ii) clasts of micrite containing hemipelagic microfauna (sponge spicules and the planktonic foraminifera *Favusella* sp.). These clasts derive from previously lithified muddy limestone, which were fractured, eroded and redeposited.

2 – 10 cm slightly marly level very rich in large black oysters;

3 – 25 cm thick limestone bed with bioturbations filled by well preserved orbitolina rich in quartz. *Mesorbitolina parva* found in this bed is Upper Aptian in age.

4 – an unconformity surface shows burrows, partly dissolved and filled by yellowish dolomite. These features are similar to superficial karst structures.

5 - 40 cm of "conglomerate" containing various rounded extraclasts, phosphatic clasts, a few planctonic foraminifera and three ammonites of Lower Albian age (*D. mammillatum* zone).

6 – The overlying unconformity is a new subaerial exposure surface with surperficial kartic cavities filled by yellowish mud.

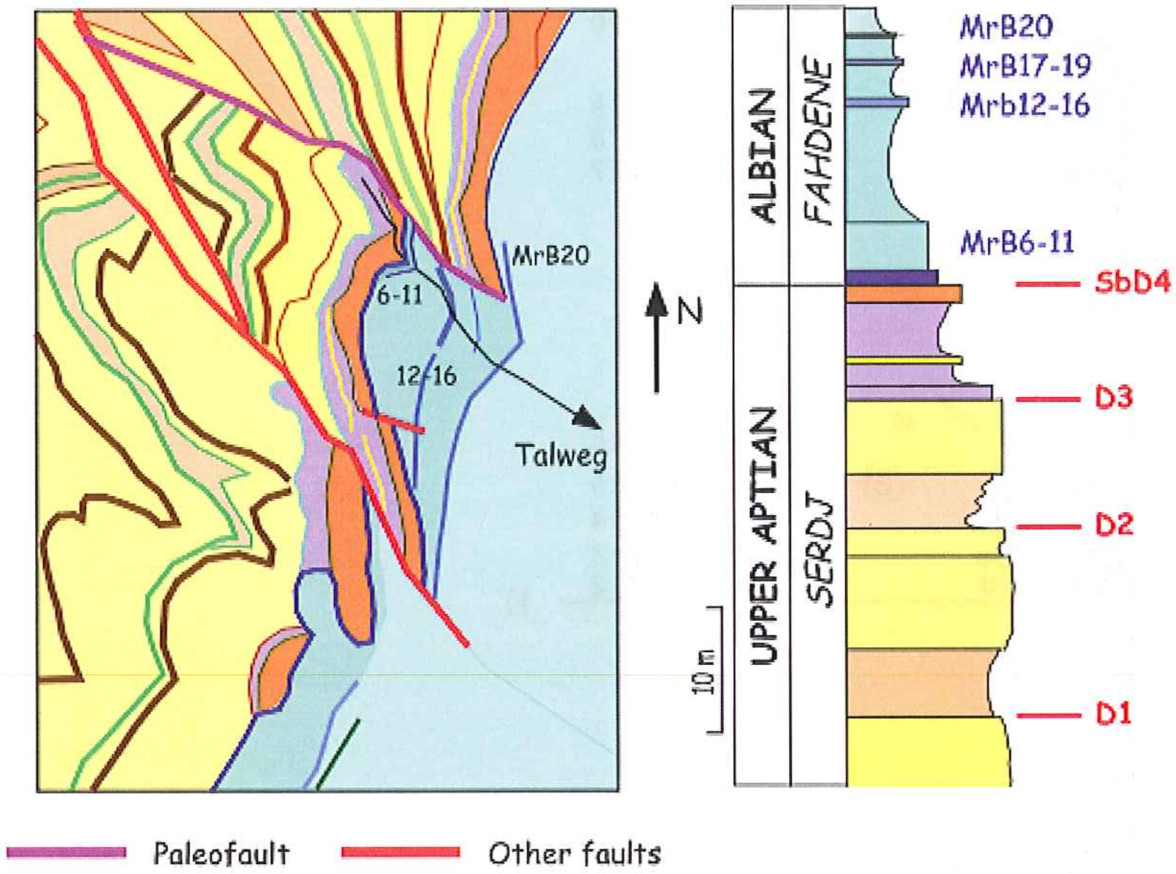

Fig. 1 – Geological map and section of M'rich graben fill

This meter thick limestone and conglomerate layer bears evidences of the following sequence of events:

1 – deposition and removing of Upper Aptian hemipelagic limestones containing *Favusella* sp.;

2 – *in situ* deposition of the well-preserved Upper Aptian benthic foraminiferas *Mesorbitolina parva*, which are preserved in bioturbations;

3 – deposition of a conglomerate composed of pebbles from various origin and associated with deeper marine faunas such as ammonites and planktonic foraminifera.

Therefore, these one meter thick deposits contains witnesses of three successive transgressive pulses, now represented only by extraclasts or pebbles. Two episodes are of Upper Aptian age, while the last one occurred in the Lower Albian. The latter is bounede by a lower unconformity, the age of which is probably close to the Aptian-Albian boundary, while the upper one is of Lower Albian age.

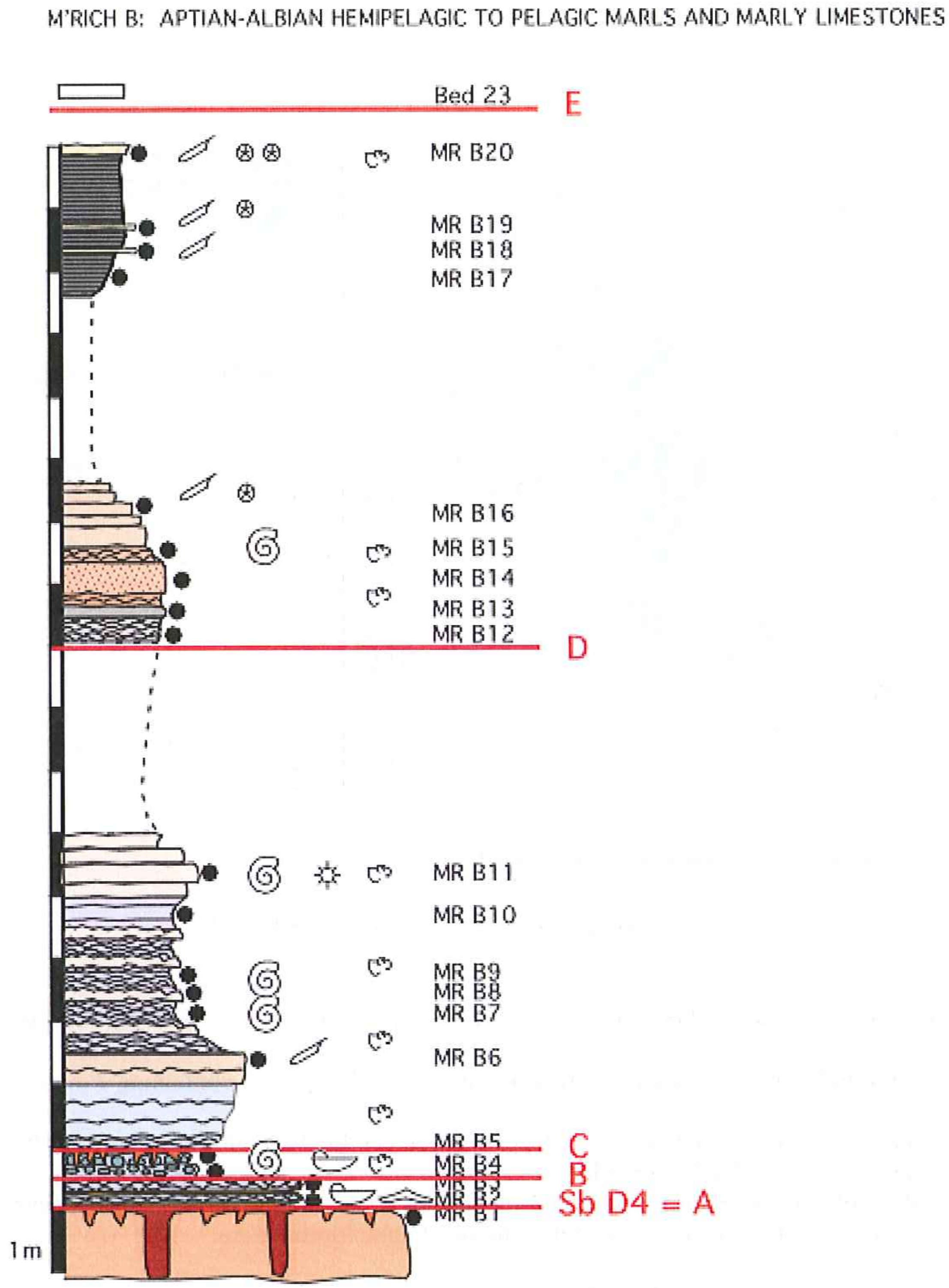

Fig. 2 – M'rich graben section sediment fill and unconformities

The pelagic-hemipelagic Albian deposits.

The overlying, five meter thick irregular bedded argillaceous limestones and marls are very rich in radiolaria and planktonic foraminifera. A few planktonic echinoderms (Roveacrinoids) were also found. Ammonites from these beds belong to the *Otohoplites auritiformis* zone, *Lyelliceras pseudolyelli* subzone (uppermost Lower Albian).

The following outcrop overlay poorly exposed marls.
The basal marly level contains abundant Favreina. This abundance is probably linked to important nutrient input favorable to benthic fauna. Bed MR B14 contains detrital quartz and very abundant Roveacrinid remains. Bed B15 is composed of reworked and phosphatized pebbles. One of the phosphatic pebbles shows cracks infilled by planktonic foraminifera and calcispheres. Two specimens of *G. ferreolensis* of Upper Aptian age (Gargasian) are also reworked, supporting the fact that pelagic or hemipelagic sediments of this age were deposited above the Serdj Fm. and then removed. This bed yielded an unidentified ammonite.
This short section ends up with three meters of black shales, which contain belemnites and crinoid fragments, as well as poorly preserved planktonic foraminifera and ammonites.

Interpretation

The preservation of a Lower Albian series, not recognized so far, within a paleograben evidences a new period of tectonic activity. Comparison of the sections observed on both sides of the paleofault, indicates that the latter was active during the Lower Albian. This paeotopography is postdated by bed 23 and the overlying Upper Albian marls, which can be followed all along the southeastern side of Djebel El Hamra.

Conclusion (Fig. 3)

Several sea level oscillations occurred between Upper Aptian and Upper Albian times. At least two of them are related to tectonic activity and creation of tilted blocks.
The offset of normal faults is documented in the Upper Aptian (probable Gargasian), and in the Early Albian.

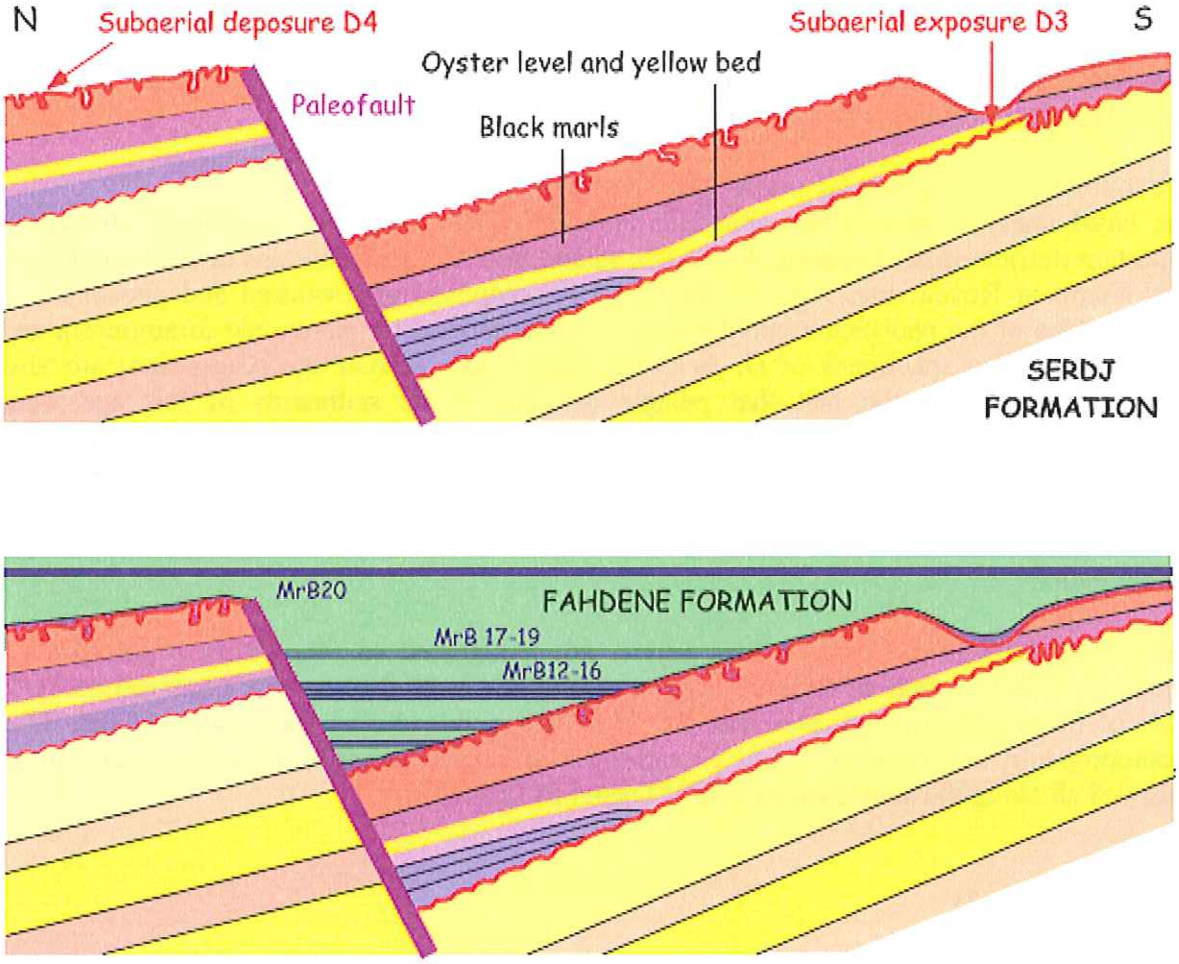

Fig. 3 – Diagrammatic cross section illustrating graben evolution

DAY 2 – JEBEL HAMEIMA - TADJEROUINE AREA

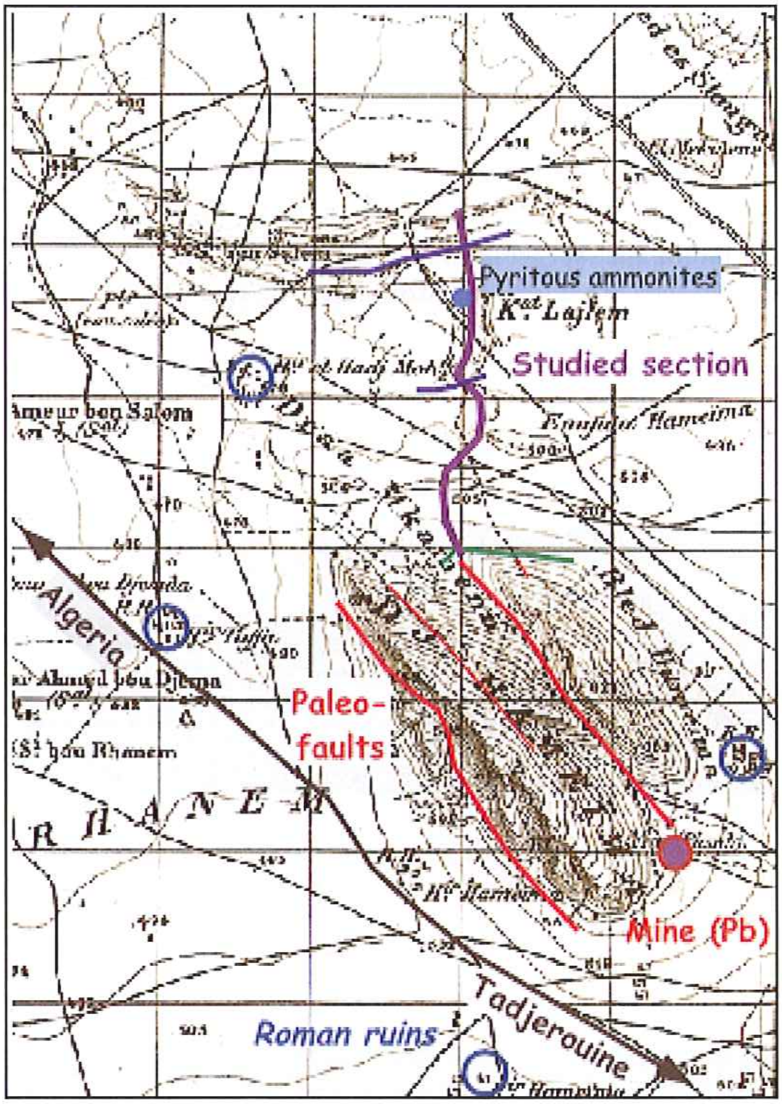

Fig C1.–Topographic map of the Djebel Hameïma, W of Tadjerouine (Western Tunisia), showing the main Upper Aptian paleofaults and the Hameima section (Hameïma and Fahdene Formations).
Note that old mine (Pb) occurs along paleofaults.

GEOGRAPHIC AND TECTONIC SETTING OF JEBEL HAMEIMA

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1) Overview :

This jebel exhibits a nicely preserved Aptian tilted block geometry, as will be shown during day 2. As in Jebel El Hamra, the Aptian normal faults are NW-SE oriented and the blocks are tilted towards the NE, but they are much less affected by compressional deformation.

Fig;1 - General view towards the NW

Fig.2 - Close up view of the investigated Aptian fault

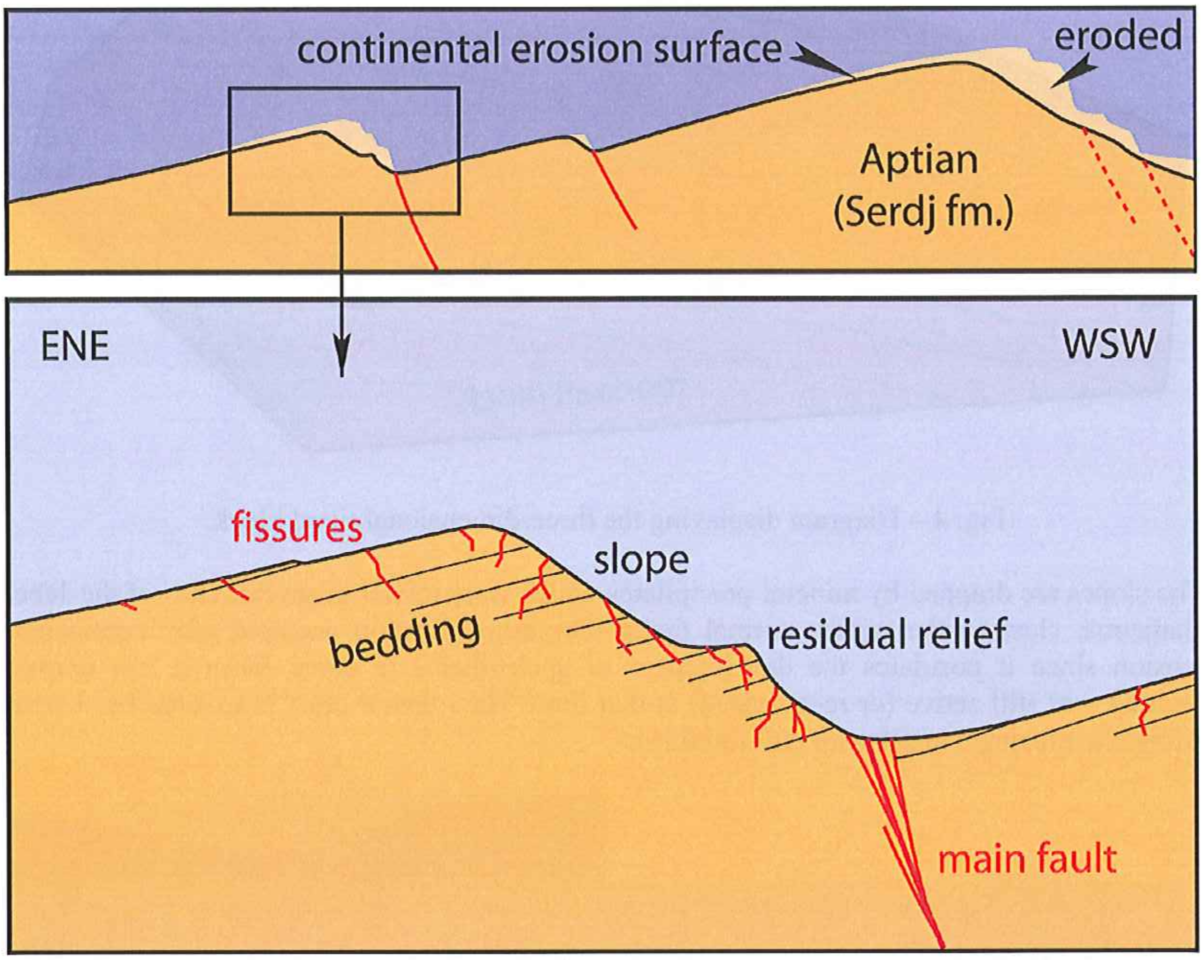

Fig. 3 – Cross section of Hameima tilted block.

The tilted blocks were created during Late Aptian times, after the deposition of the early-Late Aptian Serdj dolomitic formation, which is cut by the faults (orange, above). The resulting relief suffered continental erosion, dissolution and karstification before beeing onlapped by the Upper Aptian to Albian transgressive sediments. The pluri-decametric fault scarps show erosional morphologies due to continental exposure and their dip is significantly lower than the dip of normal faults.

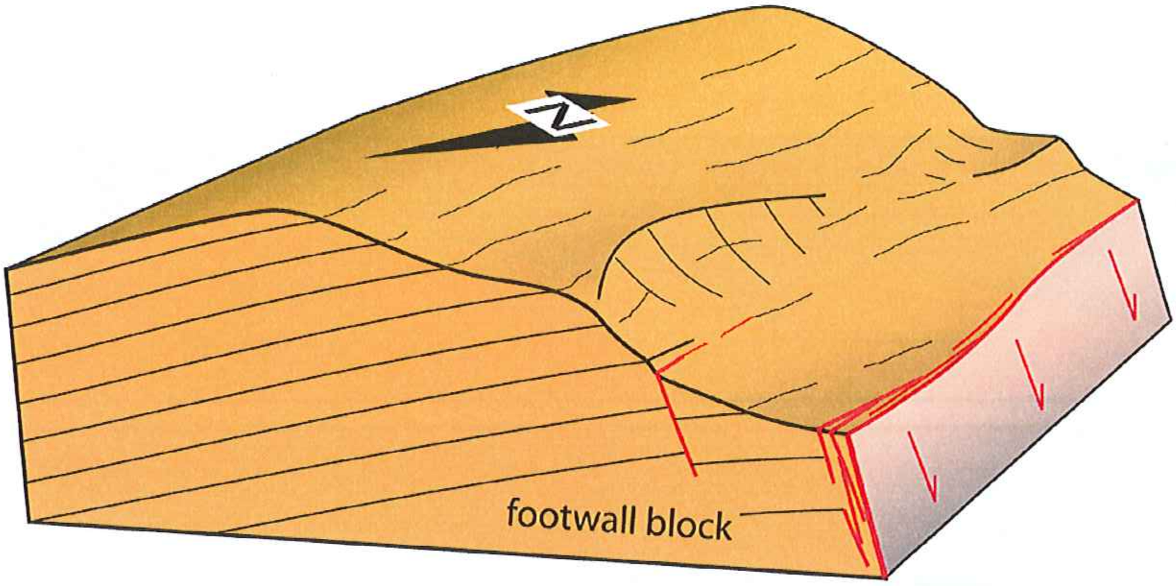

Fig. 4 – Diagram displaying the three-dimensional tilted block.

The slopes are drapped by mineral precipitates which were mined in several sites of the Jebel Hameima, close to the Aptian normal faults. The mineralization occurred after continental erosion since it postdates the development of speleothems in some fissures, but normal faulting was still active (or re-activated) at that time. The mineral crust is covered by Upper Aptian hemipelagic marls with Orbitolinidae.

Fig. 5 - View towards the NW : minor striated fault plane with mineralization in the foreground, paleoslope and major fault in the background).

Fig.7 - Close view of the low angle paleoslope, with steeper striated fault scarp in the foreground)

Microstructural data are consistent with NE-SW extension (see below), and are closely similar to the data from El Hamra. However, erosional features are more developed at Jebel Hameima, which suggest a higher relief and/or longer continental exposure than in the El Hamra region.

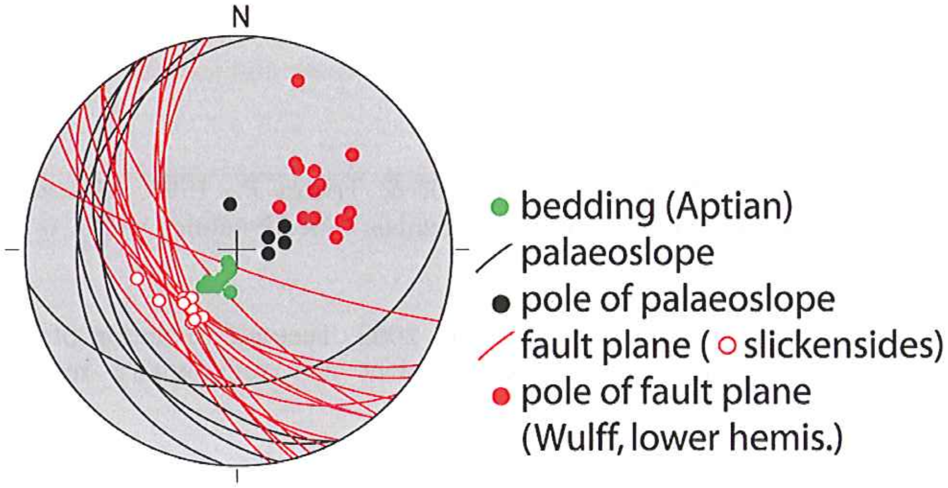

Fig. 8 – Results od microstructural analysis

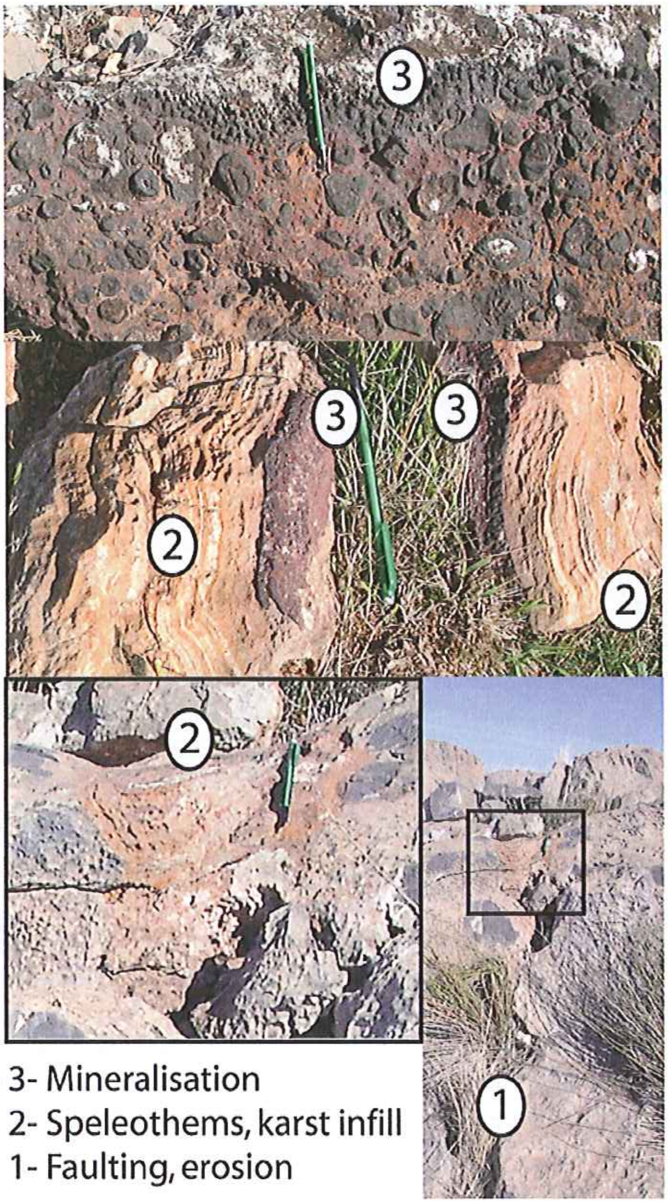

Fig. 9 - It is possible to observe a complex sequence of diagenetic events following fracturing and emersion of the tilted blocks :

1- dissolution, karstification
2- karst infill, speleothems
3- mineralization
4- and finally onlapping by hemipelagic sediments

This simplified sketch will be documented in more details on the field.

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JEBEL HAMEIMA

UPPER APTIAN TILTED BLOCKS: PALEOTECTONIC SETTING, KARSTIFICATION AND MINERALIZATION

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Location of the outcrop
Map Jebel Ouenza (1924) 1/50 000
X = 1009 600
Y = 302 300

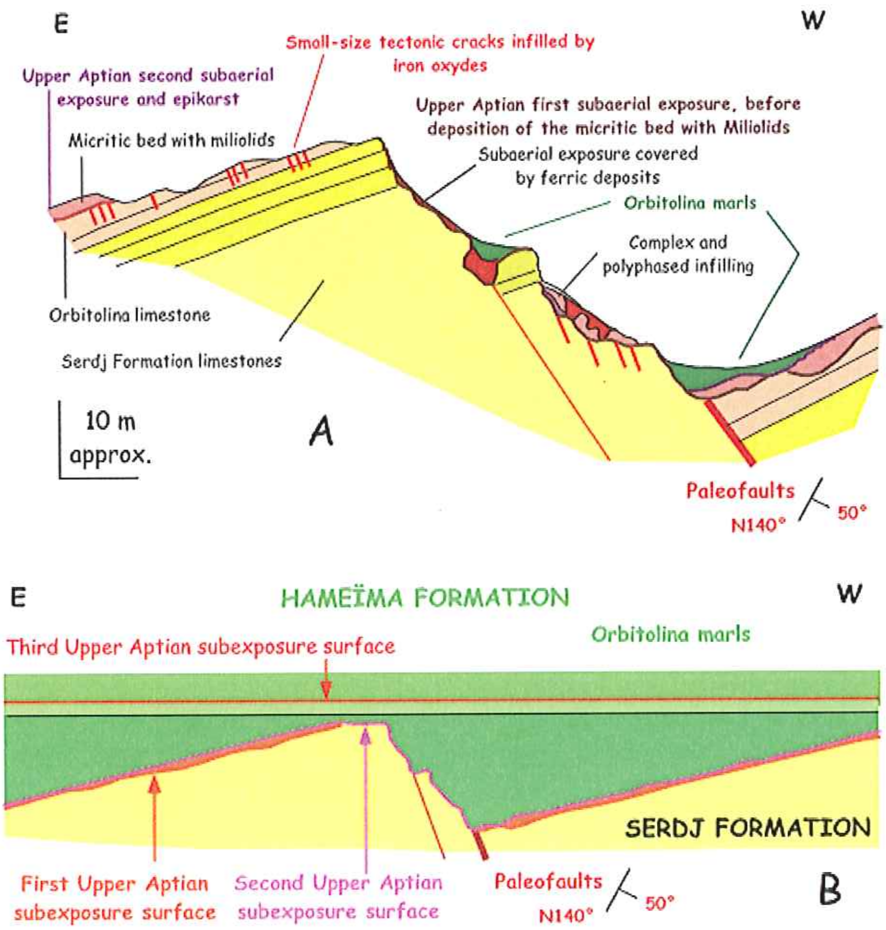

Fig. 1 – Tilted block of Hameima

This outcrop allows the detailed examination of the Serdj Fm., affected by Upper Aptian tilted block, kartification and mineralization and of the overlying sequence 3 bounded by the unconformities D3 and D4 (Upper Aptian).

Faulted block were tilted at the end of the Upper Aptian and sealed by the unconformity D3. The scenario was the same as explained for the Jebel El Hamra and M'rich outcrops. The erosional topography resulting from this tectonic episode is very uneven and shows erosional and dissolution features on the main fault plane. This paleosurface was a subaerial exposure, densely karstified during the Upper Aptian emersion. The walls and surfaces of metric karstic cavity are coated by iron crust.
A collection of karstic features can be observed:

- centimeter cave pearls (vadose pisolites),
- speleothems developed on both side of fractures,
- breccia and dripstone cement below some large angular clasts,

Clasts are altered and partially replaced by iron.

Lead and zinc ore mines deposits were exploited in Aptian limestone of the Serdj Fm since roman time. They were located in karstic cavities, close to paleofaults and are common in similar jebels of central Tunisia.
Three hypotheses might explain mineralization :

- mineralization occurs on lagoonal platform, located some distance from land, which can be the original metal source,
- mineralization is bound to areas close to evaporitic sedimentation,
- mineralization occurs in karst structures and are related to hydrothermalism.
-

Fig. 2 – Collection of kartic features and mineralization: 1, mineralized surface ; 2, dripstone ; 3, cave earl ; 4, speleothems

The two first hypotheses seem to be less probable. At that time, there is no land close to this platform and evaporites are unknown at this stratigraphic position. The third hypothesis may explain very negative δO^{18} measurements (between –6 and –10) which indicates heating during Upper Aptian – Lowest Albian times. This type of isotopic results, usually related to heating and hydrothermalism, support the hydrothermalism hypothesis mineralization..
Orbitolina bearing marls were deposited onlapping the paleotopography and filling superficial karsts of the unconformity D3.

Marls of the sequence 3 contain specimens of *Mesorbitolina parva* (Upper Aptian) and few planktonic foraminifera (*Gorbatchikella* sp.). A massive limestone bed deeply karstified and also rich in orbitolina caps them up. The top of the latter limestone bed corresponds to the unconformity D4, marked by deep karstification. We may observe the same types of karstification already described at jebel El Hamra:

- superficial karstifications filled by orbitolina – bearing sediments,
- metric karstic cavities installed on fractures. Paleo-lapiaz were developed on this subaerial exposure surface. Sedimentary fill of the cavities begins with orbitolina rich packstone and finishes with terra rossa.

The following transgression starts above the bored surface corresponding to the top of last karstified limestone.

THE HAMEIMA FORMATION

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Base of Hameima Fm (Fig. 1)

The base of the Hameima Fm. is mostly marly. Facies associations and biological content evidence an increasing water depth up to levels 12-14, then a shallowing upward trend.
Sediments deposited above D4 are rich in quartz and orbitolina (beds 4 to 6) and exhibit sandstone beds at the base. The importance of quartz input and abundance of orbitolina decrease progressively upward. Sandstones give way to blue-green nodular argillaceous limestones and marls. The fauna is represented by irregular echinoids and abundant echinoderm fragments. Presence of planktonic foraminifera (level 12-14) indicates the maximum depth. Above, facies change upward and quartz and orbitolina increased upward; this together with facies evolution indicate a shallowing upward evolution. This succession is interpreted as the first depositional sequence of the Hameima formation.
The overlying rocks are poorly exposed. The last visible outcrop shows limestone covered by iron crust and partly replaced by iron oxydes.

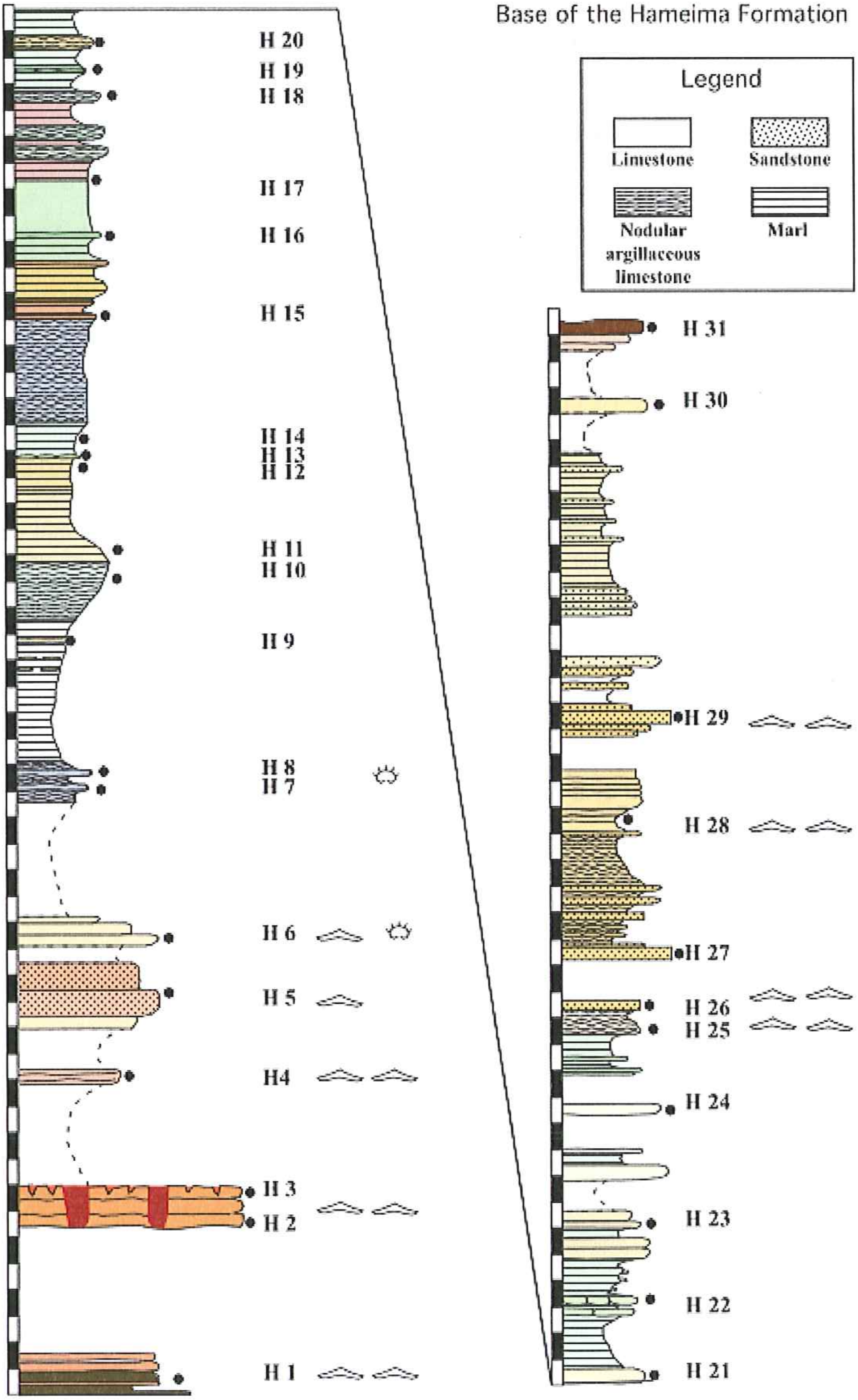

Fig. 1 – Section of the base of the Hameima formation

Top of the Hameima Fm. (Fig. 2)

The top of the Hameima fm. is formed by shoaling upward cycles composed of dolomitised limestone rich in orbitolina overlain by marl and capped by sandstone. Boundaries of cycles do not show exposure surface but are marked by bioturbations. In the first cycles, carbonates are totally or partly replaced by iron.
Progressively, the marly part of the cycles increases and eventually, form a thick marly interval (Fig. 2) capped up by massive metric sandstone beds. Three badly preserved ammonites have been found in the upper cycle, close to the top of the marls and on the top of the sandstone beds.
The occurrence of *Mesorbitolina parva* and *Praeorbitolina wienandsi* (bed 19) indicates an Upper Aptian age.
This succession corresponds to the last depositional sequence of the Hameima Fm. Although each cycle or parasequence exhibits shallowing upward evolution, as a whole the parasequence set evidences a deepening upward trend and is interpreted as a Transgressive Systems Tract. The most important marly level characterizes the Maximum Flooding Surface. Sandstones represent the Highstand Systems Tract and are probably partly eroded under the sequence boundary.
Lower Albian marls overlay this sequence boundary.

Conclusion
The Hameima Fm was deposited on a mixed carbonate-siliciclastic platform and comprises at least two depositional sequences. The age of the Hameima Fm is Upper Aptian, based on the presence of *Mesorbitolina parva* and *Praeorbitolina wienandsi.*

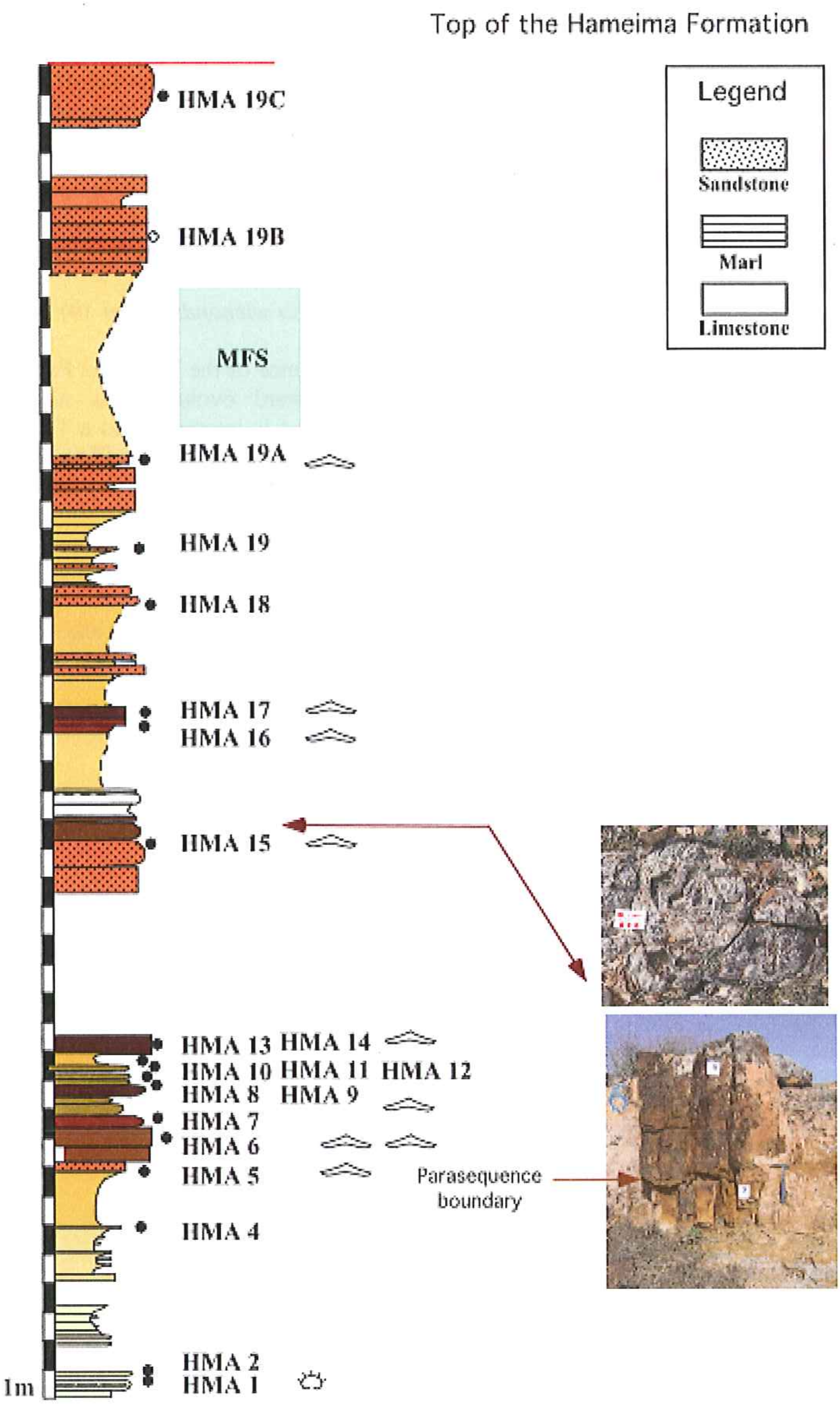

Fig. 2 – Section of the top of the Hameima formation

STOP 2

ALBIAN SEDIMENTATION IN THE TADJEROUINE AREA

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1. INTRODUCTION

The history of stratigraphy of the Tadjerouine began with Pervinquière (1907, 1912), followed by Solignac (1927) and Castany (1951), among others. The Hameima section was first dated and described in detail by Dubourdieu (1952), but Burollet (1956) first defined formally the Aptian-Cenomanian stratigraphic succession. Within the dominantly marly succession that unconformably overly the "Serdj limestones" (Aptian, locally Albian he said), Burollet (1956) defined :

- the **Hameima Formation** (310 m), made of shales, dolomites, limestones and sandstones, of approximately Late Aptian age,

- the **Fahdene Formation** (Albian and Cenomanian), mainly made of dark marls and shales, which comprises several informal units:

* ***Lower Shales*** (300 m): Dark shales and marls, beds of marly limestones, scarce beds of greywackes and limestones, of Early Albian age. The lower part includes a regionally correlatable fossiliferous level referred to as the "Ammonite horizon", ascribed to the "Clansayes zone".

* ***Allam Limestones*** (180 m): Black massive limestones, alternating with grey marls, ascribed to the Middle Albian.

* ***Middle Shales*** (280 m): Black shales and marly black limestones, dated as Late Albian.

* ***Mouehla Limestones*** (30 to 50 m): Resistant black laminated limestones of Late Albian age.

* ***Upper Shales*** (more than 1200 m): Black shales with some marly horizons. The lower part (410 m) encompasses the "Vraconnian of Cenomanian affinity" time-span, and is overlain by about 60 m of unnammed marls and limestones. Dubourdieu (1952) placed the

Albian-Cenomanian boundary close to the base of this carbonate unit. The shaly upper part (≈ 800 m) is of Cenomanian age *s.s.*.

Since then, Bismuth (1973) made a helpful synthesis of Albian stratigraphy, refining the location of faunas formerly quoted in the Hameima section, and correlating the latter with southern areas. Zghal (1994) exhaustively studied the microfossils along the Hameima section, confirming the age assignments of Burollet (1956) and Bismuth (1973). Finally, Robaszinsky *et al.* (1993a, 1993b) published detailed stratigraphic and sedimentological studies focused on the Albian-Cenomanian boundary, on sections located South of Tadjerouine, in the Azreg and Kalaat Senan areas.

During Albian times, the regional tectonic regime is thought to be dominated by a NE-SW to E-W extension, dominated by evaporite diapirs and local tilting of blocks, both controlled by inherited structures (*e.g.* Burollet and Ellouz 1986, Martinez *et al.* 1991, Zouari *et al.* 1999), although a short termed, intra Albian transpressional regime has been proposed (Bouaziz *et al.* 2002).

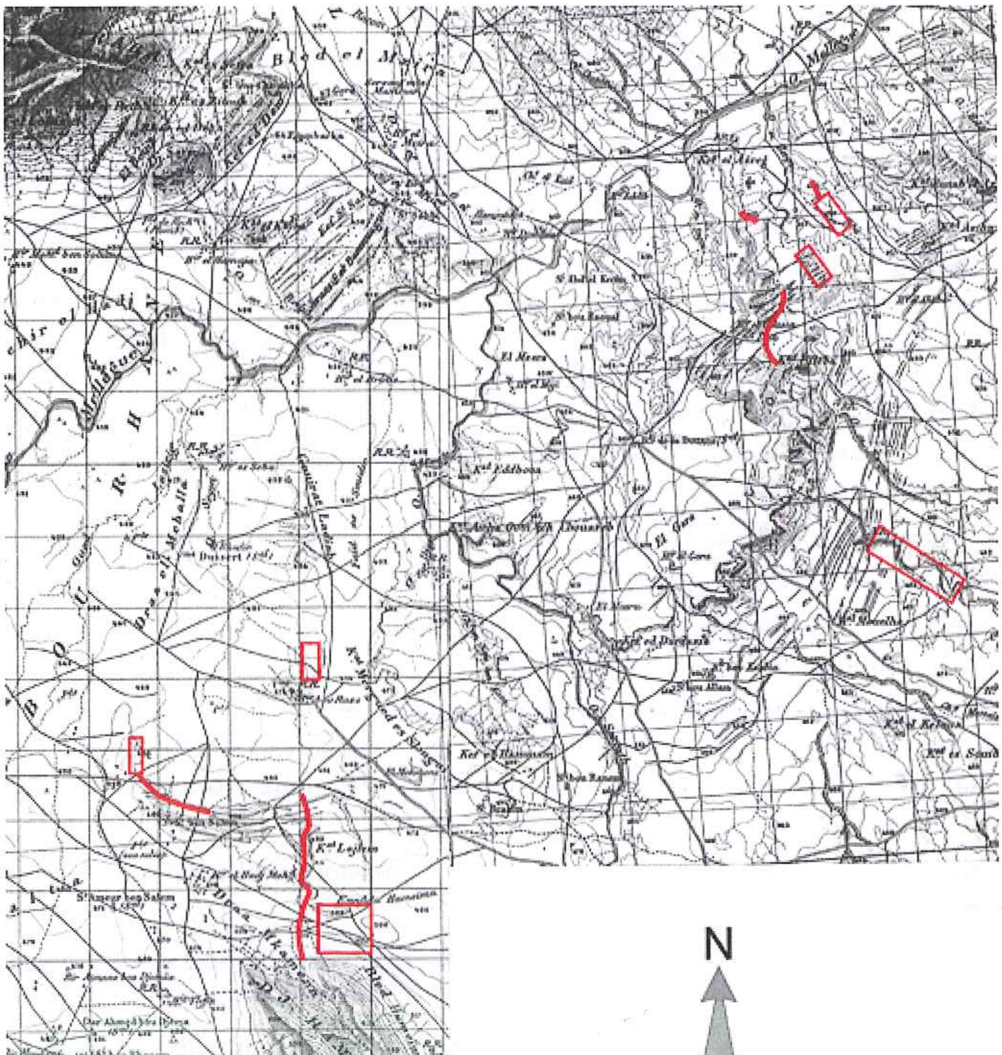

Fig. 1 - Location of the studied (bold lines) and visited sections (squares).

2. HAMEIMA SECTION (Early to early Late Albian)

The Hameima section has been studied North of Djebel Hameima between the Aptian outcrops of the Dj. Hameima and the crest located north of Sidi Ben Salem. The Hameima Fm is exposed along the river joining the Djebel Hameima and the El Feltah – Bordj de la Douane (Borj Diouana) road. The lower part of the Fahdene Fm is widely exposed South (Ammonite Horizon), and North of the latter road (Lower Shales, Allam Limestones, base of the Middle Shales). The rest of the Middle Shales can be studied farther West, North of the Marabout Sidi Ben Salem.

The upper part of the Middle Shales and Mouelha Limestones (Fahdene Fm) can be studied farther north, near the El Goussa settlement. The Upper Shales crop out near El Gara (Burollet 1956) and farther East along the Oued Es Zerga. Unfortunately, these localities do not provide exposures good enough to allow a detailed study. Only the calcareous series intercalated within the Upper Shales of the Fahdene Fm has been studied along the Oued Es Zerga, North of El Goussa.

2.A. Preliminary sedimentologic and biostratigraphic data

The Albian-Cenomanian Fahdene Fm conformably overlies fine-grained marine sandstones of the Hameima Fm and can be subdivided into several depositional sequences. This field trip will visit the Early-Middle Albian part of the Hameima section. The following description is only based on field observations. Paleontological, geochemical and environmental studies are in progress (Echihaoui, thesis in progress).

The first sequence (• 70 m) includes the "ammonite-rich horizon", and is well exposed between the Djebel Hameima and the El Feltah-Bordj de la Douane (Borj Diouana) road. It begins with a succession of sandy limestones, proceeds with shales, and ends up with shales and limestones. It can be subdivided into three minor depositional sequences.
The *first minor sequence* (• 18 m, beds 20-29) begins with yellow fine marls, which grade upwards into fossiliferous sandy limestones and calcareous, micaceous fine-grained sandstones. Within the latter (beds 25-29), bioturbations and fauna diversity increase upwards (undifferentiated bivalves and bioclasts, ammonites, oysters, pectinids (Neithea), trigonids, echinoids). Moderate currents and sporadic storms are expressed by asymetric ripples, flat pebbles and scarce Hummocky Cross Stratifications (bed 26), respectively. This unit is interpret

ed as retrogradating/transgressive (yellow marls) then progradating/regressive (fossiliferous sandy limestones). The maximum flooding surface is located within the poorly exposed yellow fine marls. However, poor outcrop conditions prevented the clear identification of an upper sequence boundary (between beds 29 and 30?). This unit yielded ammonites (beds 20-26, ?*Hypacanthoplites*, *Neodeshayesites*, ?*Parahoplites*) of Late Aptian affinity (*e.g.* Dubourdieu 1956), immediately overlain by an ammonite association (beds 27-29) of middle Early Albian age (*Douvilleiceras*, ?*Parengonoceras*, *Neodeshayesites*). This sequence is therefore ascribed to the Early Albian.

The base of the *second minor sequence* (• 38 m, beds 30-37) exhibits a deepening upward evolution, expressed by a decrease in the faunal diversity and a fining upward, retrogradational trend (beds 30-32); sandy limestones give way to poorly exposed fine shales with scarce micritic limestone nodules. This interval is interpreted as the Transgressive

Systems Tract (TST). The maximum flooding surface is approximately located between 25 and 30 m (very poor outcrops). The overlying, thickening upward succession (beds 33-37) is

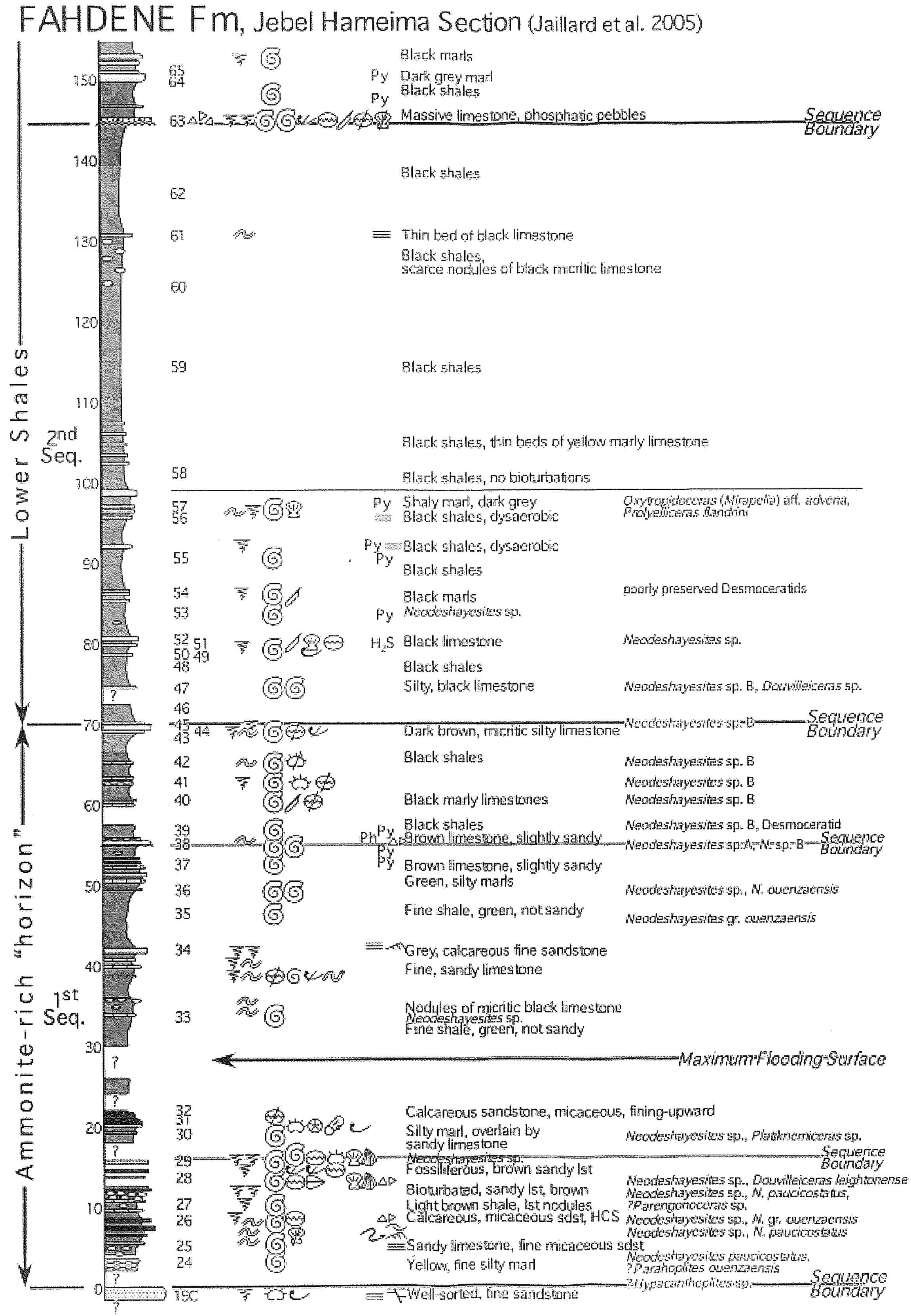

Fig. 2. Hameima section, lower part of the Fahdene Fm (Ammonite horizon and Lower Shales)

interpreted as the prograding Highstand Systems Tract (TST). It consists of green to grey shales, interbedded with thin limestone beds and scarce laminated to rippled sandy layers. The fauna is dominated by ammonites, but scarce gastropods, annelids and bivalves occur. Bioturbation is scarce. In the upper part, fine detritism appears, expressing the progradation of detrital feeding systems. Ammonites (*Platiknemiceras*, various species of *Neodeshayesites*) and the stratigraphical position indicate an Early Albian age.

The *third minor sequence* (• 15 m, beds 38-45) starts with a massive limestone bed, the base of which contains ammonite accumulations, and abundant rounded phosphatic clasts (bed 38). The lower part of the sequence is then characterized by black shales with pyrite concretions. In the upper part of the sequence, ammonites and scarce belemnites give way to shallower marine fauna (echinoids, oysters and other bivalves), while marly interbeds and bioturbation become more abundant. The upper sequence boundary is marked by a deeply bioturbated firm ground (top of bed 45). Although ammonites only belong to the *Neodeshayesites* genus, this sequence is of Early Albian age.

At a major scale, this succession may be interpreted as a single depositional sequence. In that interpretation, the 1st minor sequence would represent a Lowstand Systems Tract (LST), and the 3rd minor sequence could be viewed as a transgressive pulse within the Highstand Systems Tract.

The ***second sequence*** (• 75 m) consists mainly of black shales and corresponds to the lower part of the "Lower Shales".

It begins with an agrading succession of marls and shales (• 45 m, beds 46-57), which contains scarce open marine fauna (ammonites, belemnites, pectinids, oysters). Bioturbations are still present, while thin laminations and pyrite increases upwards. This unit yielded the last *Neodeshayesites* representatives associated with *Douvilleiceras* (Beds 47-54). The TST ends up with a poorly defined maximum flooding surface (• bed 59), which yielded an ammonite association (*Prolyelliceras flandrini*, *Oxytropidoceras* (*Mirapelia*) aff. *mirapelianum*) of upper Early Albian age (*D. mammillatum* superzone). The overlying series lacks sedimentary structures. However, the re-appearance of thin limestone beds and nodules suggests a shallowing upward trend (bed 61), which would represent the early HST deposits. This succession is interrupted by a sharp erosional surface (base of bed 63). No ammonites have been found.

The ***third sequence*** (• 98 m, beds 63-78) comprises mainly marls and shales including echinoids, ammonites, belemnites and scarce pectinids and gastropods. It corresponds to the upper part of the "Lower Shales".

The lower part (• 65 m, beds 63-72), dominantly marly, is underlain by a sharp unconformity marked by a thin limestone bed containing phosphatized pebbles (bed 63). The overlying marls first exhibit a thickening (progradational) trend, marked by the increasing number of bioturbations, echinoids and bivalves. Ammonites (*Prolyelliceras flandrini*, *Oxytropidoceras*) indicate a Lower Albian age. Then, a thinning (deepening) upward trend is associated with increasing bioturbations, belemnites and pyrite, and correlative decrease of benthic fauna (echinoids, bivalves; beds 73-74). The deepening upward trend culminates in bed 74 with the occurrence of abundant pyritic ammonites (already quoted by Pervinquière and Dubourdieu), interpreted as the maximum flooding surface.

The overlying series (• 30 m, beds 74-78) records an increase in faunal diversity and a slight thickening upward trend, and is interpreted as a progradational body (Highstand Systems Tract). Environment becomes restricted as expressed by abundant pyrite, fetid smell, sporadic laminated, non bioturbated layers, and local oil seeps. The ammonites (beds 74-78) include *Pusozia*, "*Beudanticeras*", *Prolyelliceras radenaci*, *Ptychoceras*, *Protanisoceras*, *Anisoceras* and *Douvilleiceras mammilatum*, of late Early Albian age.

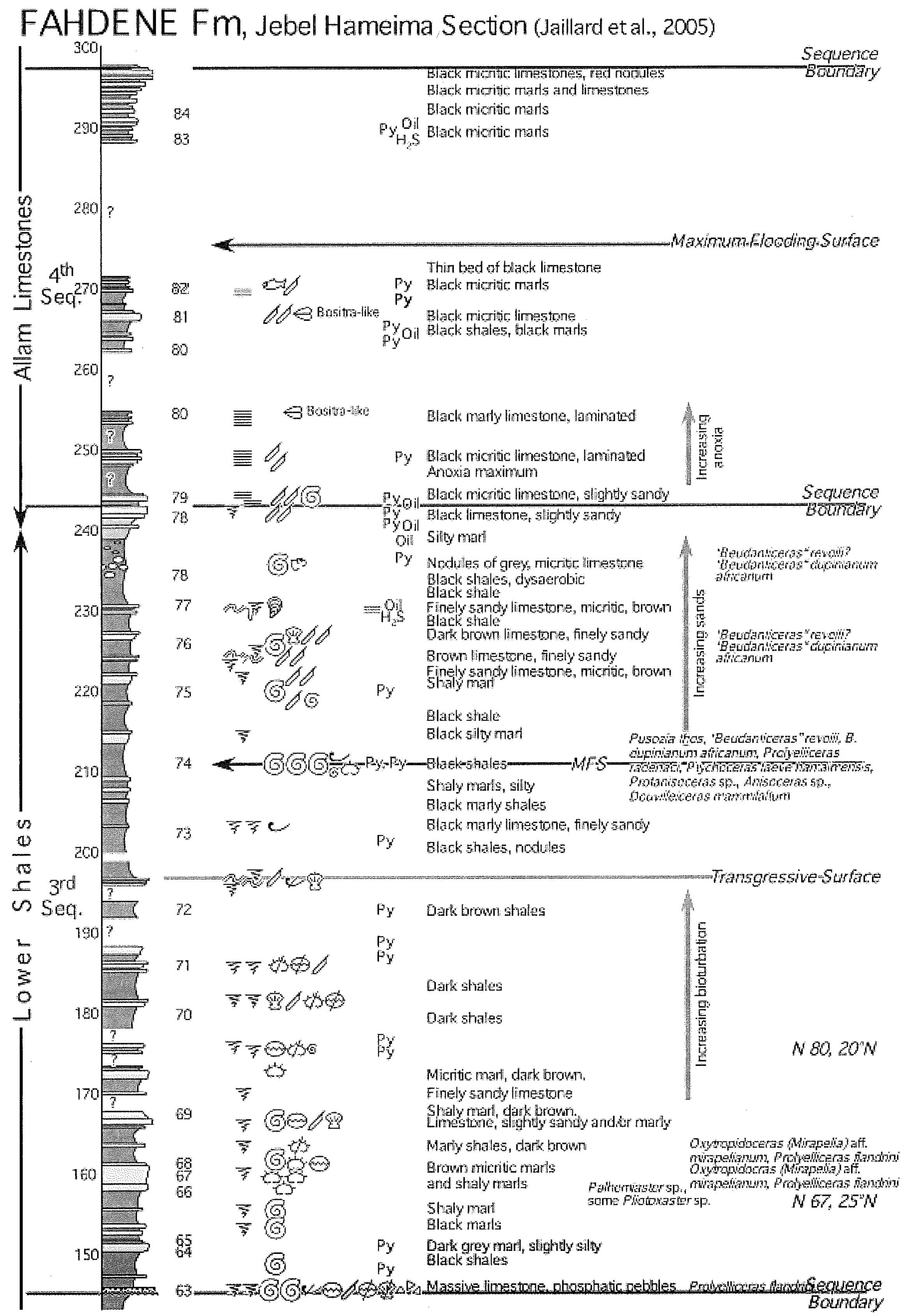

Fig. 3. Hameima section, lower part of the Fahdene Fm (Lower Shales and Allam Limestones).

The ***fourth sequence*** (• 55 m, beds 79-84) and ***fifth sequence*** (• 30 m, beds 85-86) are poorly exposed and correspond roughly to the "Allam Limestones". Both comprise a thinning upward, retrogradational lower part, and a slightly thickening upward, progradational upper part. Most of their argillaceous middle part (maximum flooding) is covered. Both sequences are marked by an anoxic transgressive interval, marked by laminated black shales, rich in pyrite and exhibiting oil seeps. Fauna is very scarce and consists only of scarce belemnites and of a small concentrically ornamented bivalve that seems to be characteristic of these anoxic environments. In spite of extensive search, no identifiable ammonites have been found so far. Burollet (1956) mentions *Pusozia* sp. The "Allam Limestones" are ascribed to the Middle Albian.

The ***sixth sequence*** (• 55 m, beds 87-107) is well exposed on the northern end of this part of the section; it corresponds roughly to the base of the "Middle Shales".

The lower part (• 40 m, beds 87-96) is a clearly thinning upward succession, which begins with anoxic transgressive layers, made of partly silicified limestones rich in laminae, ornamented bivalves and oil seeps (beds 87-88). Higher up, bivalves, belemnites, bioturbations, echinoids and ammonites successively appear, indicating transition to oxic conditions (beds 89-92). In the same way, glauconite and phosphate appear, while pyrite and anoxic indicators vanish. The ongoing deepening trend is then indicated by the disappearance of bioturbations, benthic fauna and belemnites (beds 93-95), and eventually culminates with ammonite-rich shales (bed 96). The association of *Pusozia* sp., *Hysteroceras* sp., *Oxytropidoceras* (*Oxytropidoceras*) sp., *Venezoliceras* sp., *Mortoniceras* (*Mortoniceras*) gr. *pricei* and *Mortoniceras* (*Deiradoceras*) sp. suggests an early Late Albian age. The upper part (• 17 m, beds 96-107) is a slightly thickening upward succession, bearing belemnites and ammonites, associated upward with echinoids and bivalves. It ends up with an altered yellow calcareous crust with ferruginous nodules and plant fragments, interpreted as a sequence boundary. The ammonites *Mortoniceras* (*Mortoniceras*), *Mortoniceras* (*Deiradoceras*) sp. *Hysteroceras* sp., *Oxytropidoceras* (*Oxytropidoceras*) sp., *Venezoliceras* sp. and *Neokentroceras* sp. indicate an early Late Albian age (*Mortoniceras pricei* zone).

The ***overlying series*** (• 210 m, Upper Albian) can be studied farther West, north of the Marabout Sidi Bou Salem. Several additional depositional sequences can be identified below the "Mouelha Limestones".

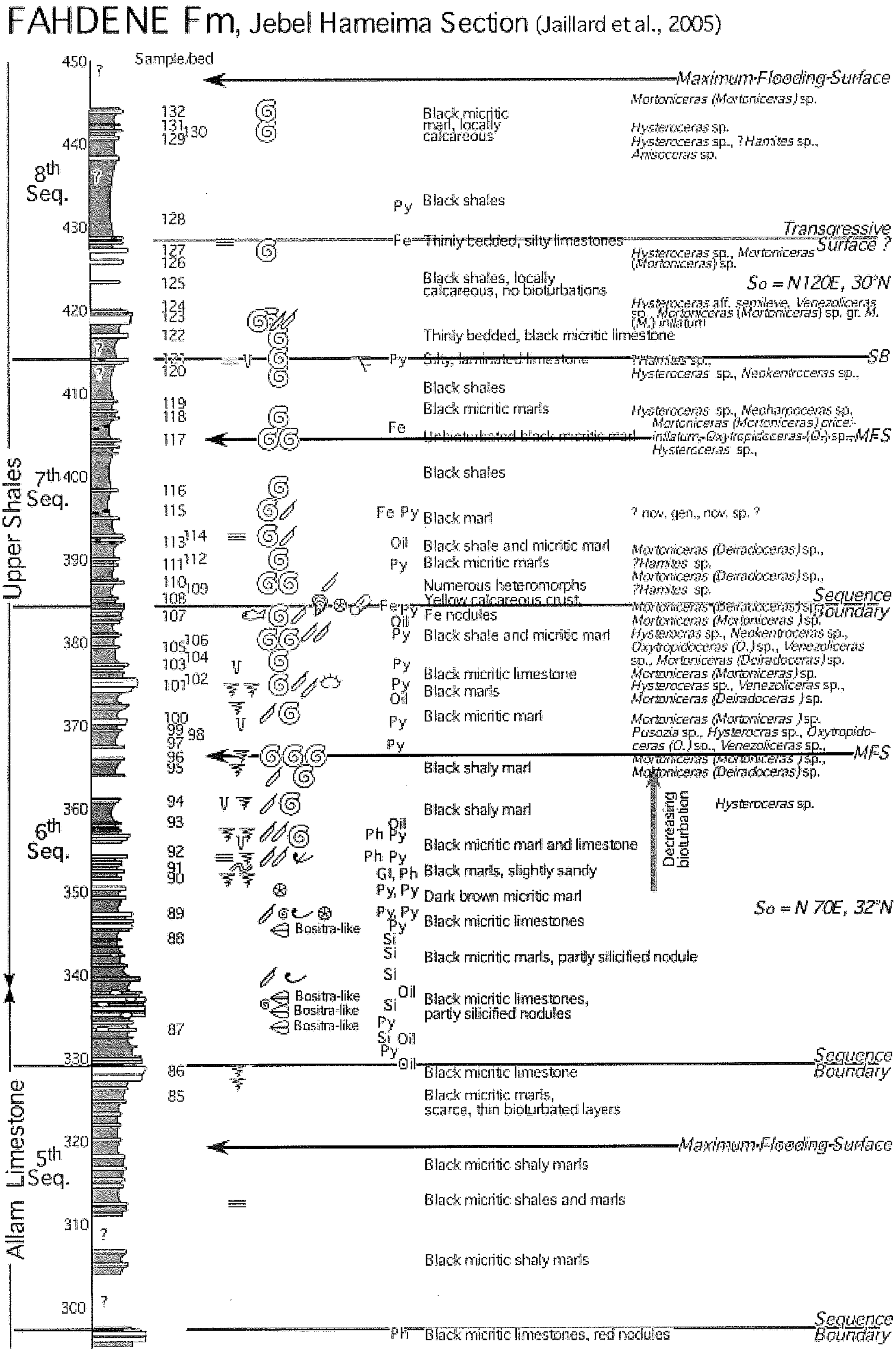

Fig. 4. Hameima section, lower part of the Fahdene Fm (Allam Limestones and base of the Upper Shales).

2.B. Notes on the environment of the Albian shelf

Except for the first described sequence, the depositional bodies are marked by common features.

Except within the lower and middle parts of the first sequence, the macrofauna associations display, from deep to shallow environments, the following succession: ammonite-bearing shales; shales or marly shales with ammonites, belemnites and inoceramids; marls with pectinids, gastropods and echinoids usually associated with the appearance of bioturbations; and marls to limestones with bivalves, pectinids and locally oysters.

This facies succession is devoid of either markers of high or even moderate energy, or slope deposits. This suggests that the Tunisian shelf was a gentle, north-deeping ramp, sheltered from most of the open marine energetic factors (tides, storms, ...), or gentle enough to significantly damp their influence.

Transgressive intervals are commonly marked by disoxic conditions, which become anoxic during the Middle Albian, and the earliest Late Albian (oil seeps). This suggests that the water column was marked by an intermediate, oxygen depleted layer, which invaded the gentle, ramp-shaped shelf during transgressions, especially the tectonically controlled depressions, if any. However, the fact that this anoxic layer is not expressed in shallowing/prograding sediments, remains to be explained.

Finally, as for the first sequence, some of the described sequences exhibit transgressive bodies, which may be interpreted as, either individual minor sequences including transgression, maximum flooding and progradation (*e.g.* 2nd sequence, beds 46-57; 3rd sequence, beds 63-72), or as Lowstand deposits *s.l.* (Lowstand Systems Tract and/or Shelf Margin Wedge). Since no clear discontinuities are recorded at the top of these bodies, they are provisionally interpreted as a LST (probable Shelf Margin Wedges).

2.C. Correlations of the Albian section of Hameima

a. With the El Hamrah section

In the El Hamrah section, Early (to Middle?) Aptian dolomites and limestones (Serdj Fm), capped by several karstified surfaces, appear to be overlain disconformably by early Late Albian marine deposits, evidencing a period of hiatuses and condensed sedimentation of several million years. However, hemi-grabens locally contain whitnesses of Middle Aptian (?) to Middle Albian (?) deposits (Arnaud-Vanneau *et al.*, this volume).

Above the deeply karstified "D4 = A" surface, conglomerates rework open marine micrites and are overlain by limestones bearing pelagic foraminifers and Early Albian ammonites (MRB 2 and 3, *D. mammillatum* zone), equivalent to those of the 1st sequence of Hameima. This first sequence ends up with a new karst surface (SB), referred to as "surface B".

The latter is overlain by transgressive calcareous marls, which yielded ammonites among which *Lyelliceras pseudolyelli* indicates the latest Early Albian (MRB 7 to 11). The overlying shaly marls are covered, and probably encompass the MFS, possibly of earliest Middle Albian age, and probably equivalent to the lower part of the "Allam Limestones" of the Hameima section (4th sequence). This sequence is in turn capped by a new Sequence Boundary.

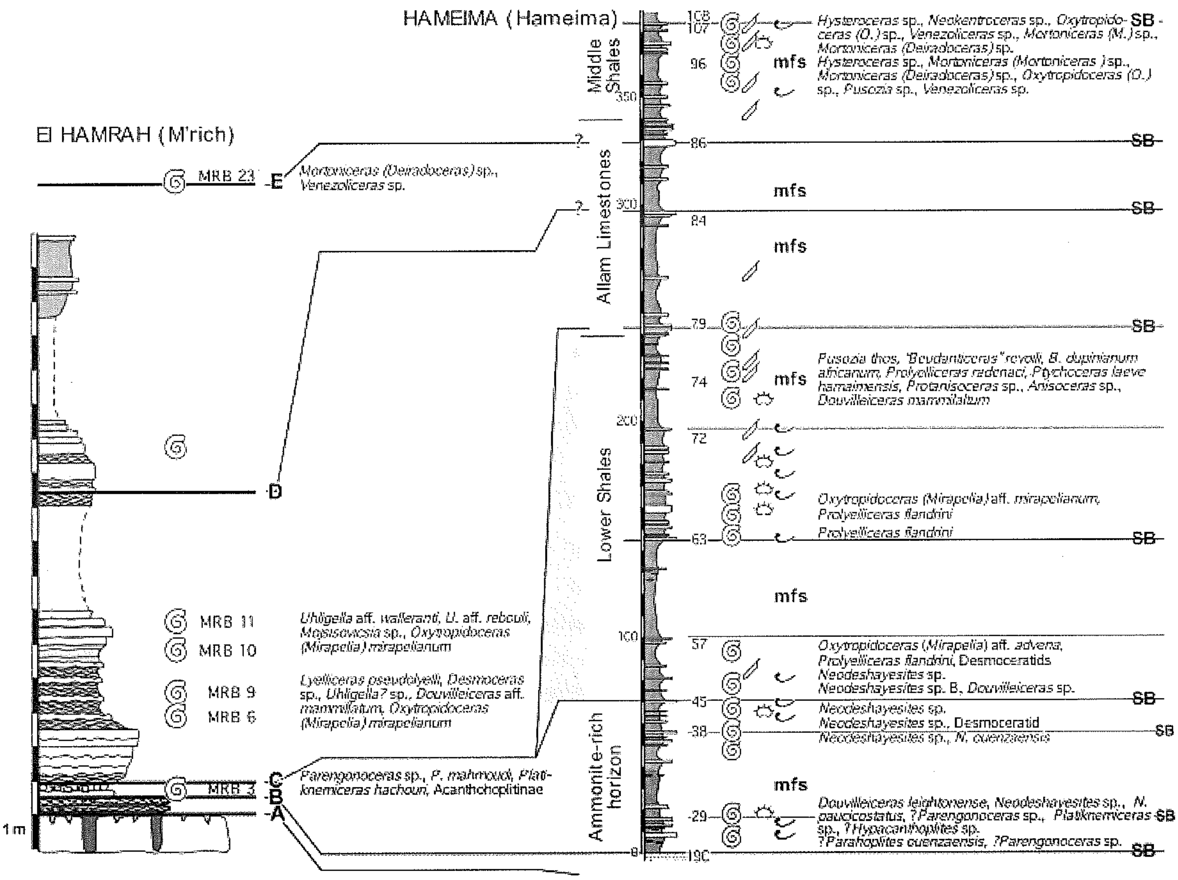

Fig. 5. Tentative correlations between the lower parts of the El Hamrah and Hameima sections

The overlying transgressive calcarenites and conglomerates are overlain by calcareous marls and then by shaly marls (covered). The overlying fossiliferous bed (MRB 23) yielded ammonites of the *M. pricei* zone, possibly equivalent to the association found in the upper part of the 6th sequence of the Hameima section.

Therefore, the El Hamrah section registered three major Maximum Flooding events, of middle Early Albian, latest Early Albian-earliest Middle Albian, and early Late Albian age, respectively. As these events are also recorded in the Hameima section, they allow preliminary correlations. According to this preliminary stratigraphic framework:

- Surface A (= D4) and B of El Hamrah would contain the Hameima Fm of the Hameima section,
- Surface C of El Hamrah would comprise the 2nd and 3rd sequence (most of the Lower Shales) of the Hameima section,
- Surface D of El Hamrah would encompass the 5th sequence ("Allam Lst" *p.p.*) of the Hameima section,

- Surface E (top of bed 23) of El Hamrah would correlate with the base of either the 8th, or the 9th sequence of the Hameima section,
- the ≈ 25 m thick section of the El Hamrah section certainly correlates with the ≈ 450 m thick section of the Hameima section.

b. With the south Tethyan Andean Basin (Peru, Ecuador)

This succession exhibits striking similarities with those of other south-Tethyan areas, especially with the Andean Basin, which belongs to he same plate as Africa, until the definitive opening of the southern Atlantic Ocean in the Late Aptian.

In Peru for instance, the Early Albian Inca Fm (≈ 100 m, *D. mammillatum* zone, equivalent to the Hameima 1st sequence) overlies thick, undated clastic shoreline deposits, and comprises also three sequences (Robert 2002). The first one is dominantly sandy, and its upper part yielded, besides andean taxa (*Douvilleiceras*, *Neodeshayesites*), an ammonite fauna of american and cosmopolitan affinity (*Beudanticeras*, *Desmoceras*, *Hamites*); the second one is mainly carbonated and yielded mainly andean ammonite species (*Desmoceras*, *Douvilleiceras*, *Neodeshayesites*); the third one ends up with open marine carbonated lithofacies.

The base of the overlying sequence (base of the Chulec Fm, equivalent to the 2nd sequence in Hameima) is dominated by cosmopolitan ammonite taxa (*Desmoceras*, *Glottoceras*, *Mosjisoviczia*, *Parengonoceras*, *Prolyelliceras*, *Ralphimlayites*, *Tegoceras*), expressing a major transgression of late Early Albian age (Robert 2002).

The early Middle Albian major transgression is widely represented by anoxic deposits in the Andean basin (Pariatambo Fm, Robert 2002), which constitute source-rocks in the eastern areas of Peru (*e.g.* Jaillard *et al.* 1994, Mathalone and Montoya 1995). In Peru, the transgression is marked by the first occurrence of *Lyelliceras pseudolyelli* (top of the Lower Albian), and the immediately overlying anoxic levels contain locally very abundant specimens of *Lyelliceras lyelli*, *Ralphimlayites ulrichi*, *Oxytropidoceras* (*Mirapelia*) spp., *O.* (*Oxytropidoceras*) spp. and *O.* (*Benavidesites*) spp. of earliest Middle Albian age (Robert 2002). In the same way, in southeastern Ecuador (Chinimbimi), the "middle Albian" major transgression is marked by a high organic matter content and by the occurrence of *Brancoceras aegoceratoides*, *Lyelliceras* gr. *ulrichi-mathwesi*, *Oxytropidoceras* (*Mirapelia*) sp., *Oxytropidoceras* (*O.*) *boesei-hubbardi*, and *Glottoceras* spp., while the HST is marked by a restricted association of species of *Oxytropidoceras* (*O.*) spp. and *Glottoceras* spp. (Bulot, *in* Jaillard *et al.* 1997). Unfortunately, equivalent faunas have not been found in Hameima, although this time-span should be represented within the anoxic lower part of the "Allam Limestones" (4th sequence).

The early Late Albian major transgression (6th sequence of Hemeima) is also well known in the Andean basins, where it represents the maximum extent of marine sedimentation on the margin; these deposits constitute good source-rocks in the Eastern Basins (Raya and Basal Napo fms, *e.g.* White *et al.* 1995, Mathalone and Montoya 1995, Jaillard *et al.* 1997). In Ecuador, the transgression is marked by the occurrence of *Brancoceras* (*Brancoceras*), *Oxytropidoceras* (*O.*) *carbonarium* and *Venezoliceras* gr. *venezolanum*, associated with *Aucellina* sp., of late Middle Albian age. The overlying early Highstand Systems Tract (20 m higher) yielded various species of *Dipoloceras (Dipoloceras)* and *Glottoceras*, associated with *Actinoceramus concentricus*, indicating an earliest Late Albian age (*D. cristatum* zone, Bulot *et al.* in press). The maximum flooding surface therefore would coincide roughly with the Middle-Late Albian boundary.

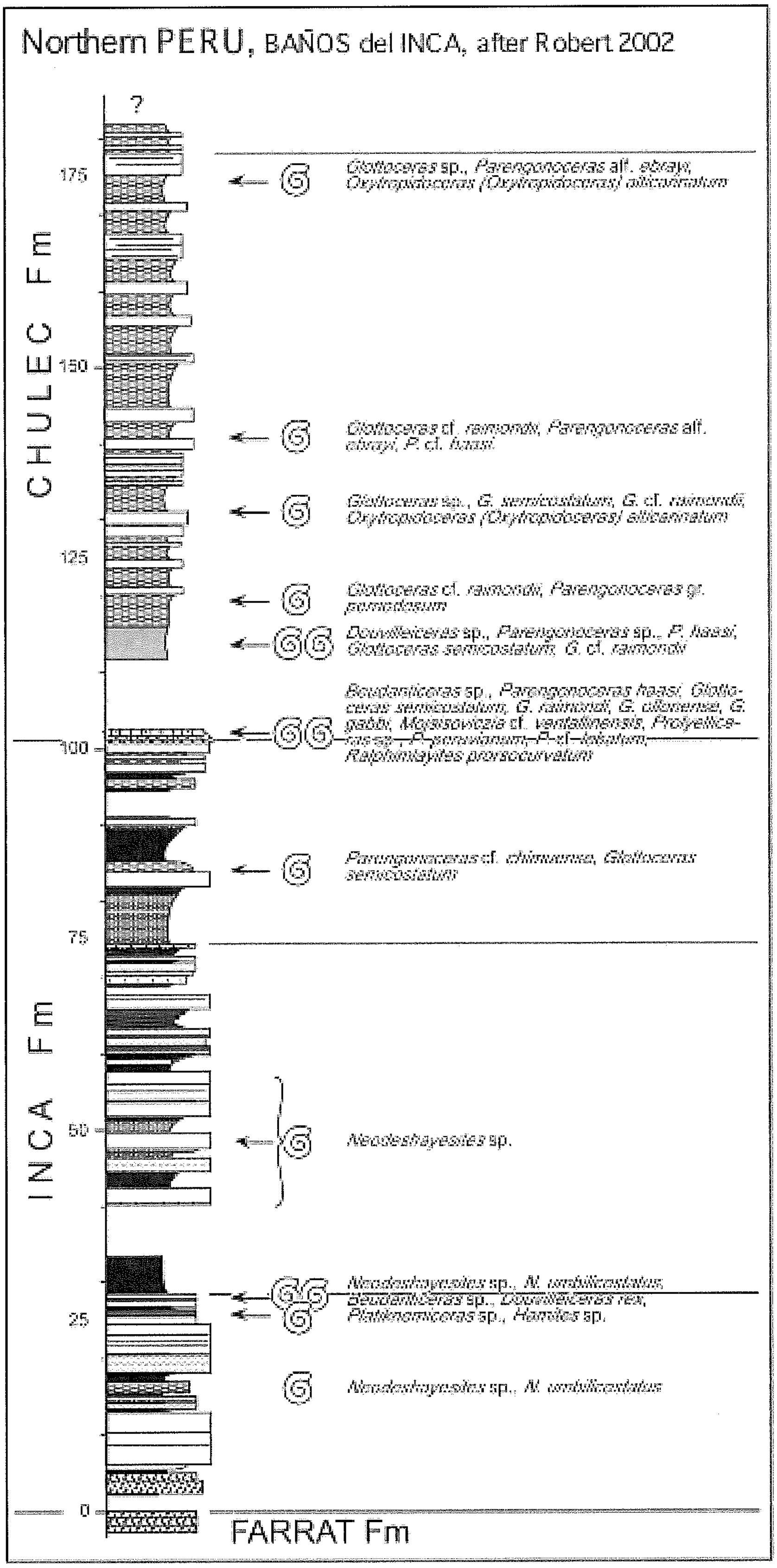

Fig. 6A. Ammonite succession and main sequences of the Baños del Inca section, northern Peru, after Robert (2002)

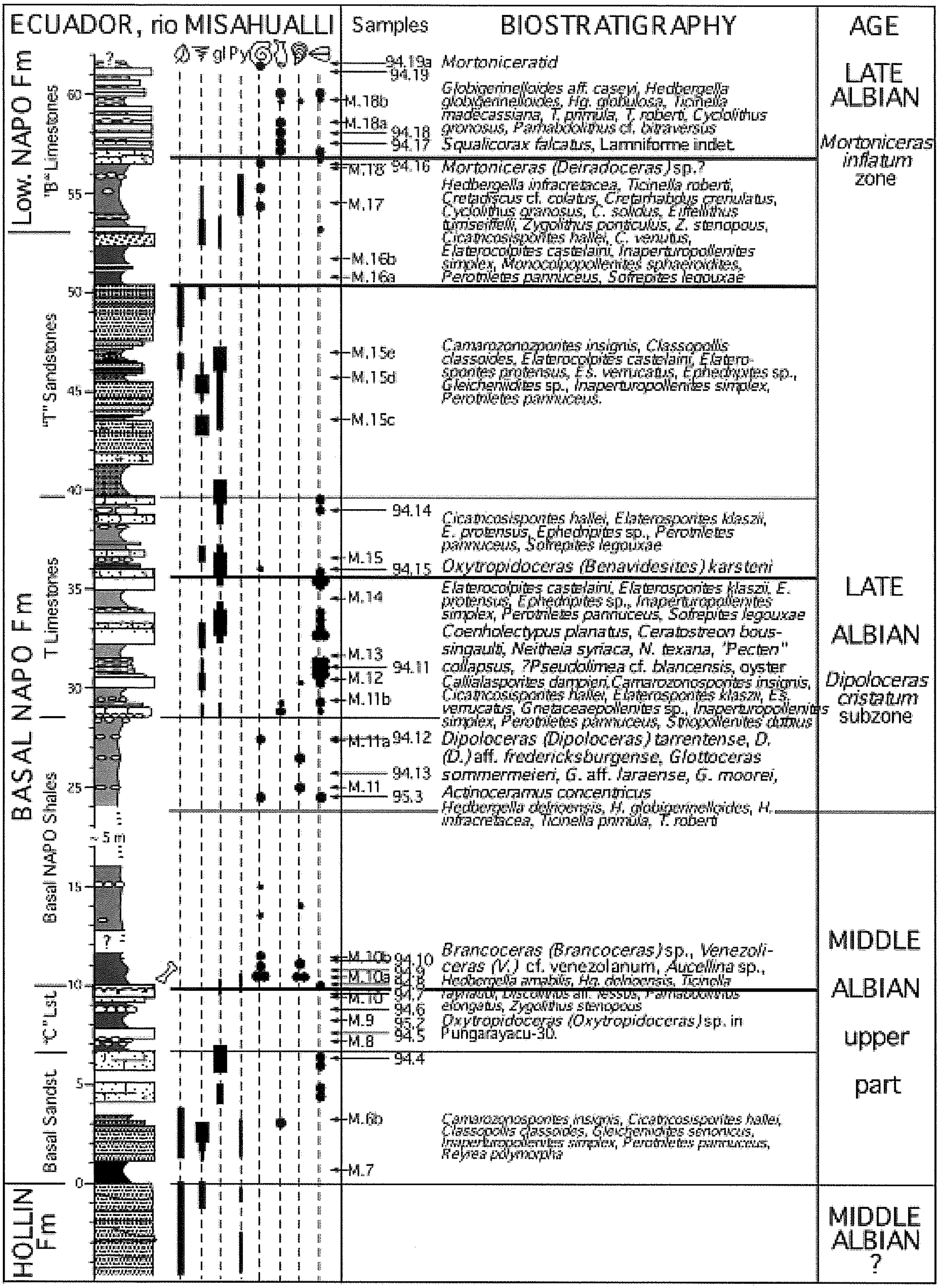

Fig. 6B. Ammonite succession and main sequences of the r4io Misahualli section, eastern Ecuador, after Jaillard (1997) and Bulot et al. (2005).

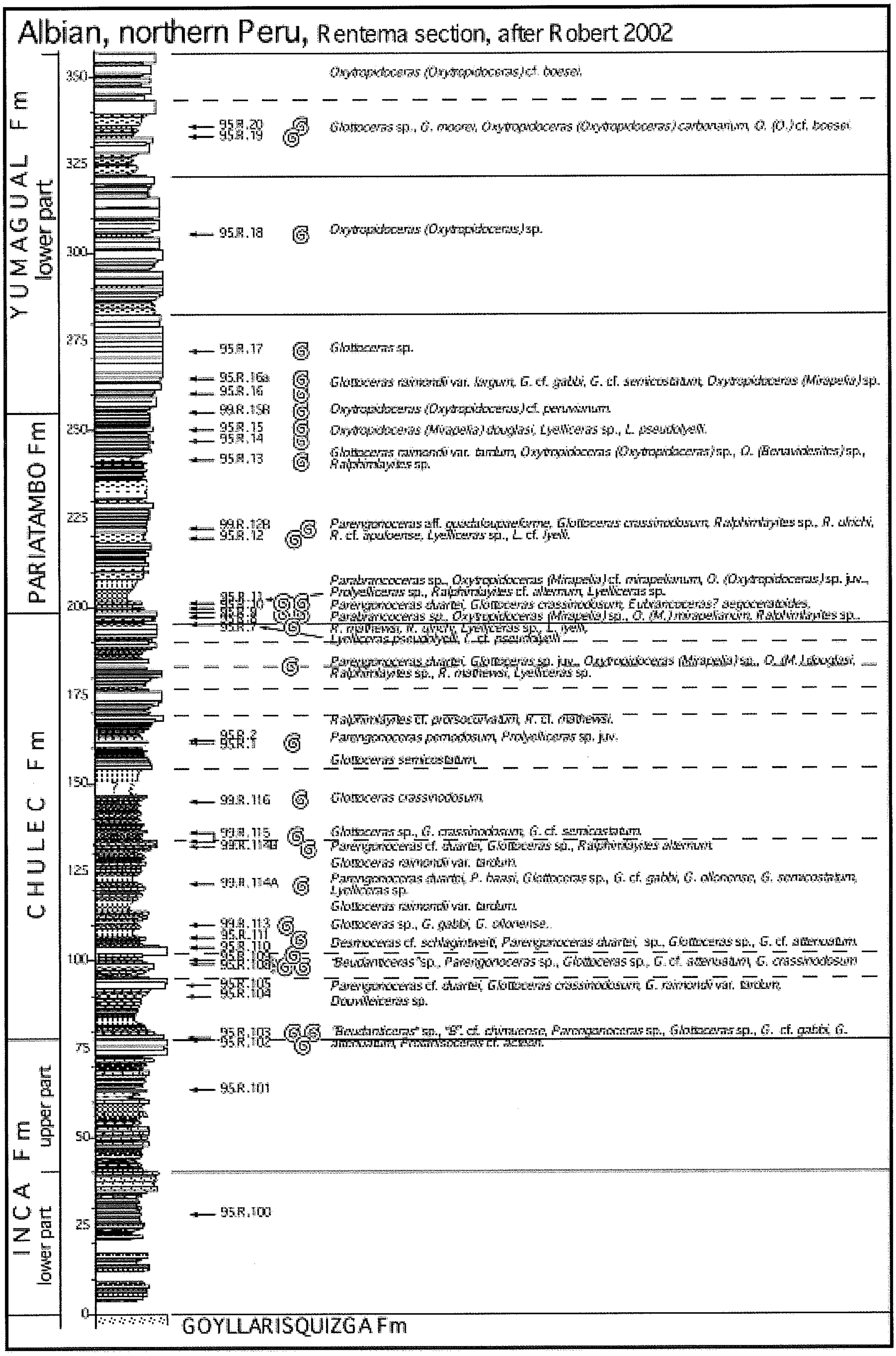

Fig. 7. Albian ammonite succession in the Rentema section (north Peru), after Robert (2002).

3. OUED ZERGA SECTION (Albian - Cenomanian boundary)

The Albian – Cenomanian boundary (part of the Fahdene Fm) has been studied north of Djebel Hameima, along the Zerga river (Oued Zerga, Fig. 1). The upper part of the section is exposed on the left bank of the valley, while the lower part is better exposed on the left side. Preliminary results allow to intent interpretations, and correlations with the sections (Azreg, Smarra) studied farther south by Robaszynski et al. (1993). Ammonites are moderately preserved, but planktonic foraminifers are abundant and well-preserved. However, the presented determinations result from a first reconnaissance, and need detailed studies, especially about the definition of the *Rotalipora "brotzeni"* and *R. "globotruncanoides"* species.

3.1. Preliminary data on the Oued Zerga (El Goussa) Section

The Oued Zerga (El Goussa) section can be divided into three main parts (Fig.8).

The poorly exposed lower part (0-11 m) consists mainly of fine-grained, monotonous black shales, containing pyrite and scarce ammonites of latest Albian age, interpreted as a distal, deep shelf sedimentation. A reconnaissance through the underlying comparable black shales evidence a rather continuous and monotonous sedimentation, suggesting a HST.

The middle part of the section (11-60 m) is marked by an alternation of dark shales and marl or limestone beds. Regarding sedimentological features, this unit is marked by the appearance and increasing number of detrital quartz, shelf fauna and bioturbations. The occurrence of bioclasts, bivalves, echinoids, ostracods, and scarce rudists and gastropods, associated with more abundant planktonic ammonites, belemnites, foraminifers and radiolarias, suggests a shallower, middle shelf environment. In some more detail, two subunits may be identified:

* The lower subunit (11-36 m) is marked by the lack of limestone beds, the scarcity of detrital quartz, benthic fauna and bioturbations, and the thickening-upward shape of the marly interbeds. This suggests that progradation is the dominant sedimentary process. Ammonite association is dominated by latest Albian fauna. However, beds 1 to 3 bear abundant *Rotalipora "brotzeni"* and *R. appenninica*, while *Rotalipora globotruncanoides* are abundant from bed 4 upwards, indicating that the Albian-Cenomanian boundary is located no hugher than bed 4.

* In the upper subunit (36-60 m), the fauna, bioturbations and detrital quartz are more abundant and varied, the calcareous beds exhibit sharp basal contacts and locally a thinning upward trend; additionally, oblique laminations and channel-type obliquity may be observed locally. This suggests that deposition is at least partly due to reworking, and that this part represents the shallowest environment in this section. Typical Cenomanian ammonite assemblages are recorded from bed 14 upward. Nevertheless, *Rotalipora globotruncanoides* is present throughout the subunit, although with variable abundance, thus indicating an Early Cenomanian age.

The third part of the section (60-98 m) consists of a thinning-upward sequence of shales and marls, marked by the lack of bivalves, echinoids and other benthic fauna and bioturbations. Scarce ammonites dominated by species of *Mantelliceras* sp., would belong to the *Mantelliceras azrengensis* and *Mantelliceras cobbani* subzones defined by Amedro (*in* Robaszynski et al. 1993). In the lower part, detrital quartz is still abundant, while pyrite dominates in the upper part. Along the right side of the Oued Zerga, large-scale contorted beds interpreted as a slump can be observed in the lower part of this unit (~ 62-70 m). This unit is interpreted as a retrogradational successions culminating with distal, deep shelf environments.

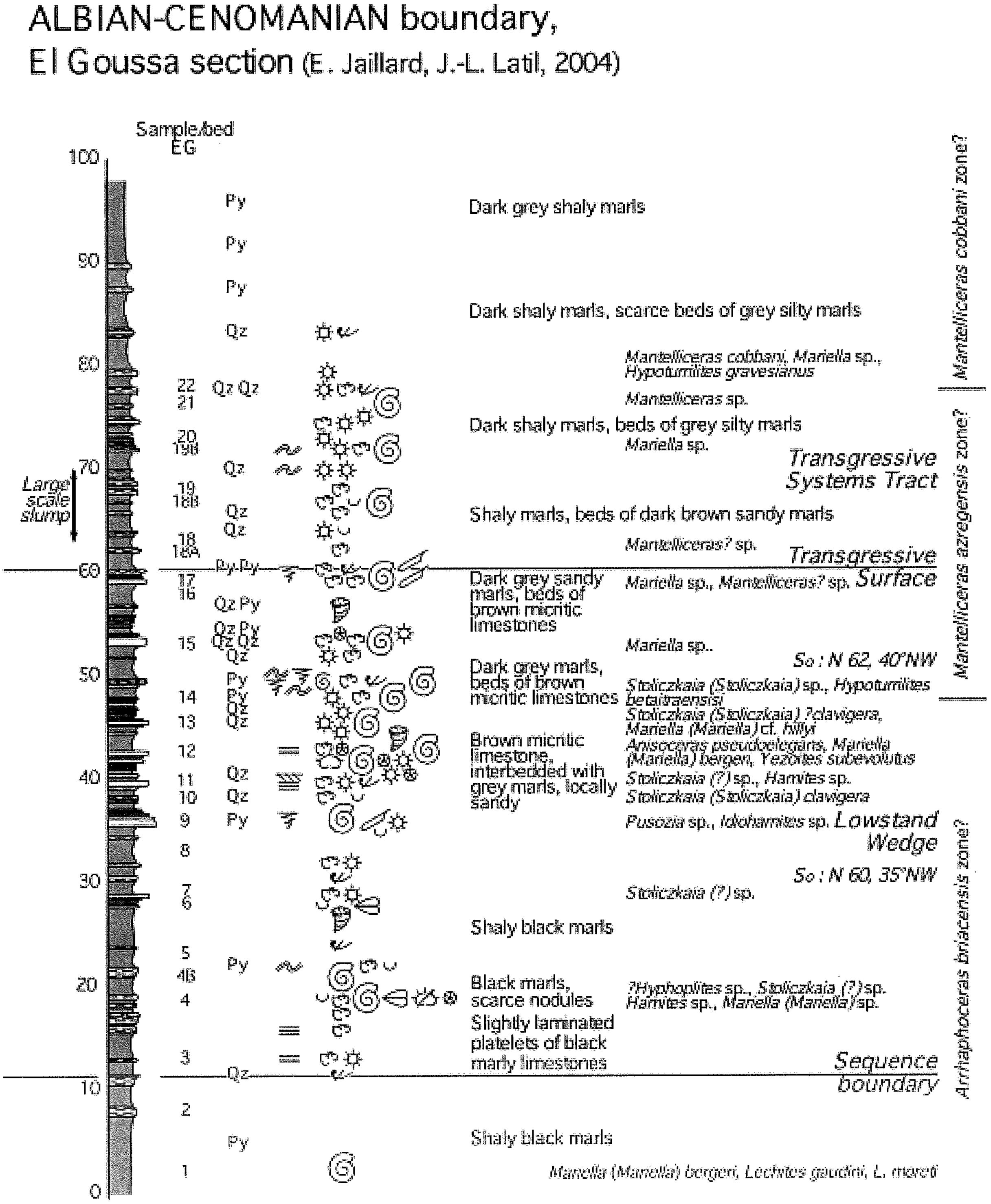

Fig. 8. Ammonite succession in the Azreg Member of the Oued Zerga section (N. of El Goussa).

In summary, (1) the lower part of the section is intrepreted as the HST of a poorly exposed latest Albian (?) depositional sequence; (2) the middle part is regarded as a LST of a new depositional sequence, the base of which (Sequence Boundary) is tentatively placed at meter 11 (appearance of marly beds, detrital quartz and scarce bioclasts); (3) the upper part of the section is interpreted as the TST of the upper sequence. The Albian-Cenomanian boundary is preliminarily placed at bed 4, but might be slightly lower.

3.2. Correlation with the Azreg Section

The Azreg section has been studied in detail by Robaszynski et al. (1993), visited by us during field work, and will be presented during this field trip (Robaszynski, this volume).

There, the section can be divided into 2 depositional sequences (Fig.3). The HST of the first sequence (-68 to -14 m) is made of monotonous black shales bearing sparsed gastropods, bivalves and urchins, together with abundant ammonites. Abundant pyrite and scarce bioturbation and benthic fauna indicate restricted (disaerobic?), though not anoxic bottom conditions. Two distinct ammonite assemblages are provisionnally ascribed to the *Mortoniceras (Subschloenbachia) perinflatum* and *Stoliczkaia (Shumarinaia) africana* subzones, respectively. This unit is correlated with the lower unit of the Oued Zerga section.

The LST of the overlying sequence is marked by a thickening upward succession exhibiting marly and then limestone interbeds. The Sequence Boundary is placed at the base of the first marly beds (-14 m), and is marked by the appearance of detrital quartz, and an increase in benthic fauna. The lower part of the LST is correlated with the equivalent subunit of the El Goussa (Oued Zerga) section (11-36 m). Ammonites from this subunit would belong to the *Stoliczkaia (Shumarinaia) africana* subzone, the age of which would be latest Albian-earliest Cenomanian (Gale et al. 1996). No data on planktonic foraminifers are available so far.

The upper part of the LST (Az.0 to Az.5) is marked by the occurrence of spectacular, large-scale smooth erosional channels, usually infilled by fine-grained calcarenitic limestones, interpreted as the transit zone between the shelf, emergent and eroded during low sea-level, and the distal shelf or basin (Robaszynski et al. 1993). No data on planktonic foraminifers are available so far. Typical cenomanian ammonite assemblages appear at bed Az.2, although the Albian-Cenomanian boundary, defined by the first occurrence of *Rotalipora globotruncanoides* (Gale et al. 2002), would be slightly below. As a consequence, the channelized interval of the Azreg section is considered equivalent to the calcareous upper LST of the El Goussa (Oued Zerga) section (36-60 m). In this interpretation, the Oued Zerga section, located north of the Azreg section would represent the site of deposition of the reworked sediments that transited through the Azreg zone, which acted at a slope (channelized unit) during the LST.

Along the Azreg section, the Transgressive Surface, located at the top of the calcareous interval (bed Az.5) is overlain by a thinning upward succession of marls and shales, the base of which exhibits ammonite-rich phosphatized horizons, ascribed to the *Mantelliceras azregensis* and *Mantelliceras cobbani subzones* (Robaszinski et al. 1993). This TST is correlated with the thinning upward upper unit of the El Goussa (Oued Zerga) section, where the same ammonite subzones have been identified. In this interpretation, the presence of phosphatic beds in the Azreg section would be due to condensations on the slope zone, while the Oued Zerga area would have been located downslope.

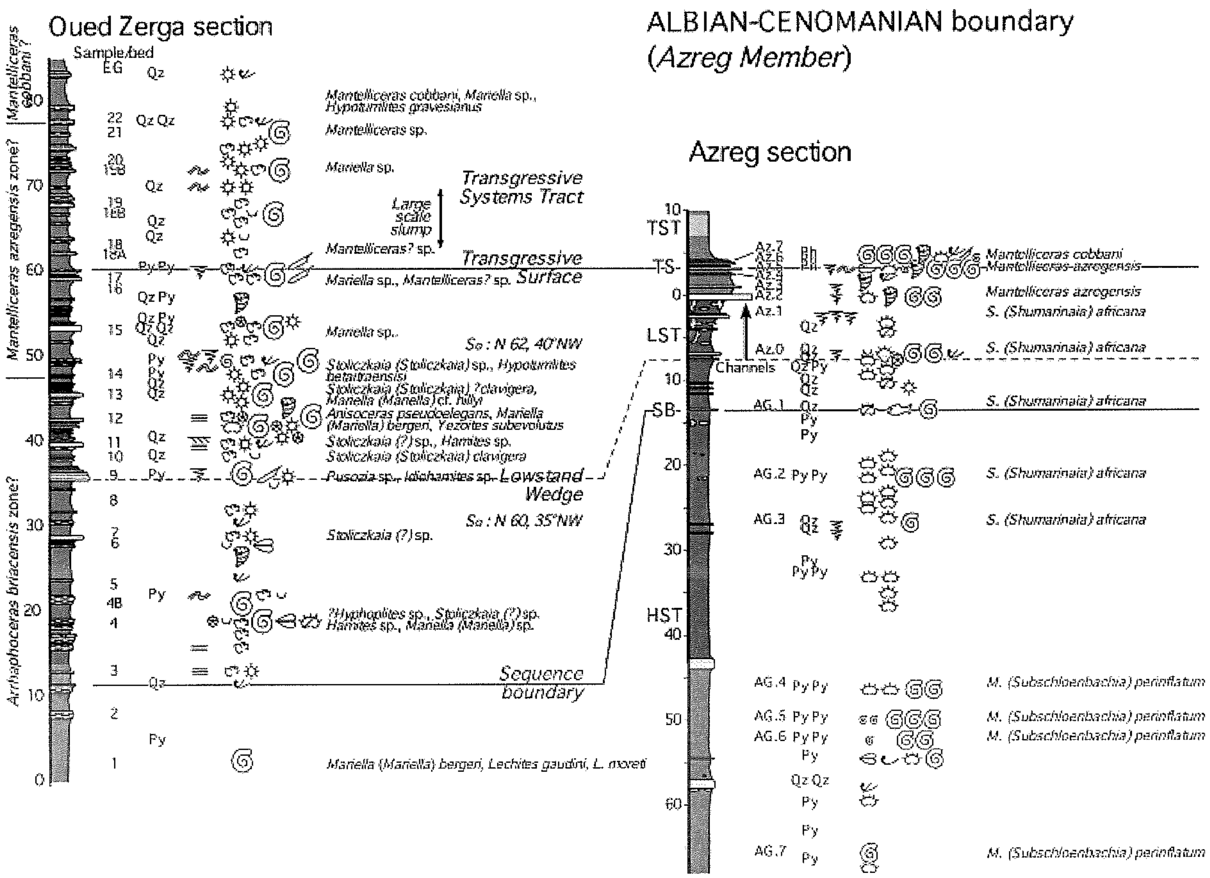

Fig. 9. Proposed correlations between the Oued Zerga and Azreg sections.

According to classical models, channels and slumps mark the early LST. The delay between the channels and the beginning of the LST observed in the Azreg and Zerga sections may be due, either to an acceleration od sea level drop, or, rather, to slight tectonic movements. Indeed, the latter interpretation would account for the occurrence of a slump in the early TST.

3.2. Conclusion on the Albian-Cenomanian boundary in the Tadjerouine area

The Albian-Cenomanian boundary is marked by a significant sea level drop, expressed by a well-developed LST. Such a low sea level period near the Albian-Cenomanian boundary may explain the lack of latest Albian deposits in most Andean sections.

However, the occurrence of channels and slumps in the late LST and early TST instead of in the early LST, suggests that this sea level drop was associated with slight tectonic events. The South-North facies evolution suggests that the tunisian ramp is marked by a mild slope located near Azreg, evidenced there by erosional channels and phosphatic, and by deeper environments and reworking accumulations in the Oued Zerga section.

Finally, more sedimentological and biostratigraphic studies are necessary in order to refine the ages and interpretations presented here.

Acknowledgements

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DAY 3 - THE CENOMANIAN OF THE KALAAT SENAN AREA AND ITS LOWER AND UPPER BOUNDARIES

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ABSTRACT

The Cenomanian of the Kalaat Senan area consists of 655 m of sediments deposited in a distal environment. The position of the lower and the upper limit of the stage follow the recommendations proposed in 1995 during the Brussels Symposium on the Cretaceous Stage Boundaries. The base of the stage is defined with the first presence of the planktonic foraminifera *Rotalipora globotruncanoides* (*R.brotzeni* of authors), and the top with the first presence of the ammonite Watiroceras sp.(at this time, the index species *W. devonense* was not found in Tunisia).

The aims of the first thirst day field meeting are to visit the Albian-Cenomanian boundary in the Kef el Azreg area (KZ section), then to see the Middle-Upper Cenomanian succession and the Middle-Upper Cenomanian boundary at the Kodiat Dellal (KD section) and, to end, to visit the Cenomanian-Turonian boundary in the Bahloul formation, and the Lower Turonian in the Smara wadi (SM section).

The paleogeographic position of the Kalaat Senan Cenomanian succession is transitional between the plate-forme and the basin and favours the development in the sediment column of all system tracts. If sediment supply is adequate, lowstand, transgression and highstand systems tracts should develop.

INTRODUCTION

At a paleogeographical point of vue (Fig.1), the Cenomanian sediments of the area visited are in a very distal environment, in a transitional position between a plate-form (carbonates and evaporates South of Kasserine) and a deep basin towards the North-West (Tunisian trough of el Kef and N. Algeria).

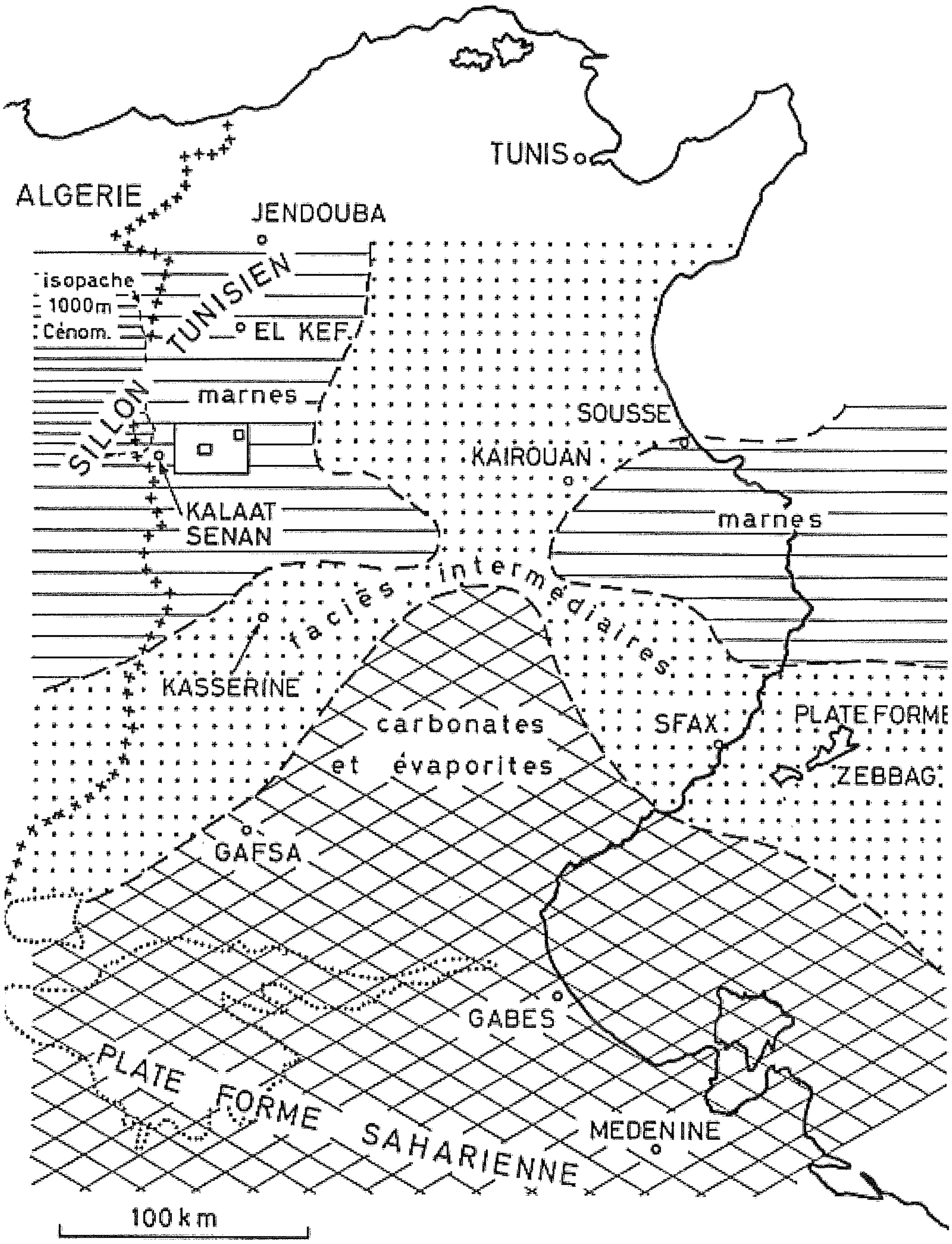
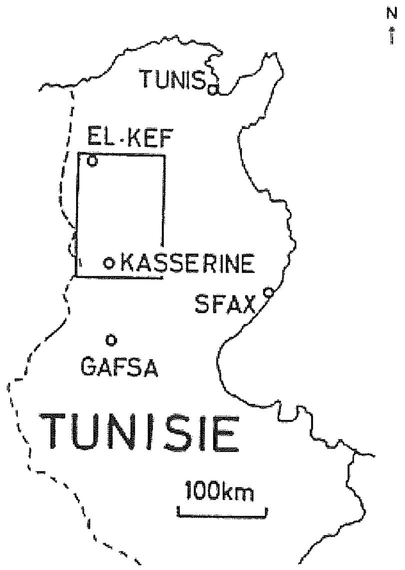


Fig.1- The Kalaat Senan area (rectangle) in the Cenomanian paleogeographical contaxt (in Robaszynski et *al.,* 1994)

The area visited is geographically situated in Central Tunisian (Fig.2), in or near the Kalaat Senan-Jerissa-Thala triangle. It corresponds to the North-West part of the Tunisian Atlas, very North of the Saharian platform and South of the diaper zone.



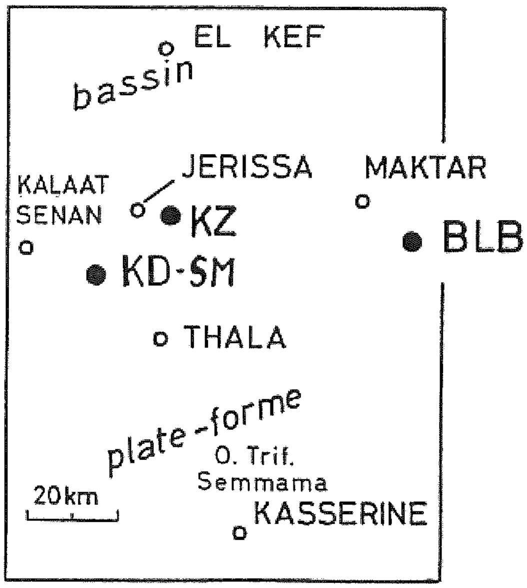


Fig2- Location of the sections in central Tunisia

The lithostratigraphical context of the sections visited in given on (Fig.3) where the Cenomanian appears as the upper part of the marly Fahdene Formation and a part of the Bahloul formation.

About the lithology, the Cenomanian section of the Kalaat Senan area consists almost entirely of marly basinal deposits with only a minor, albeit essential, in flux of platform derived sediments. Platform derived carbonate beds are rare in the lower and the middle part of Cenomanian succession, but become more numerous in the upper part (KD section).

A composite lithological succession is drawn for the Cenomanian of the Kalaat Senan area from a dozen of partial sections as indicated in the Fig.4 which shows the position of the section to be visited or discussed: KZ and SMA, KD and partly SM.

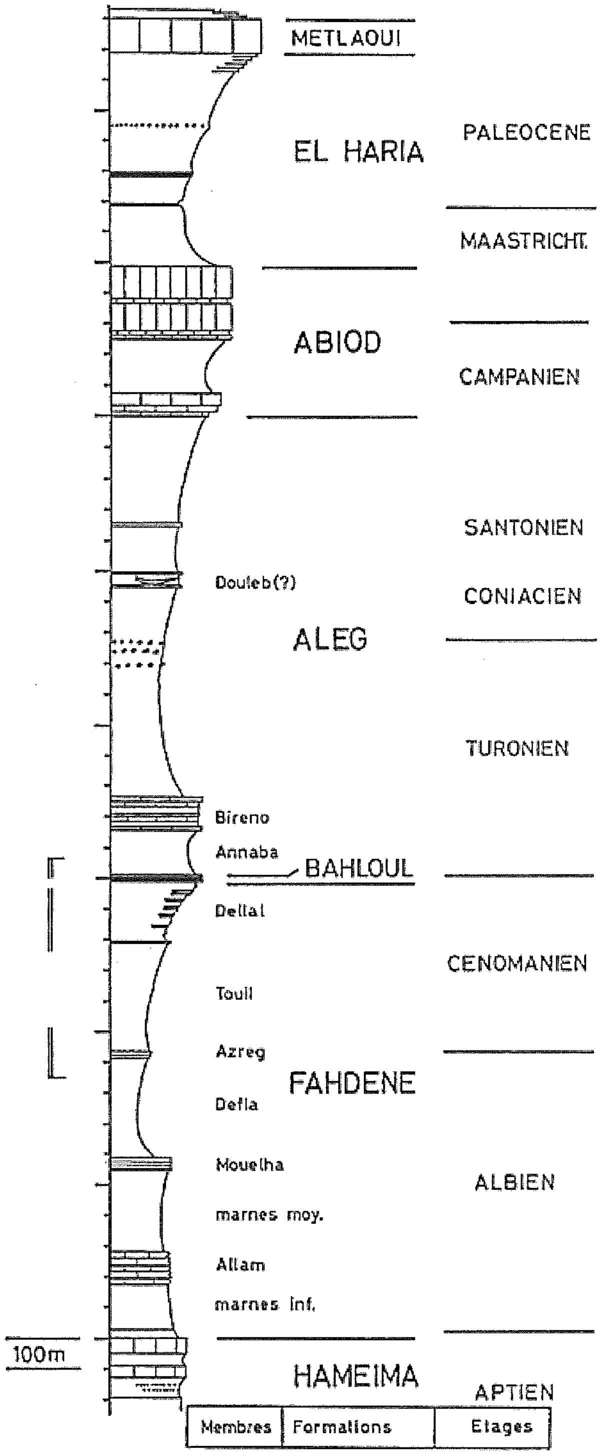


Fig.3- Situation of the visited intervals in a simplified lithological succession of the Cretaceous in the Kalaat Senan area

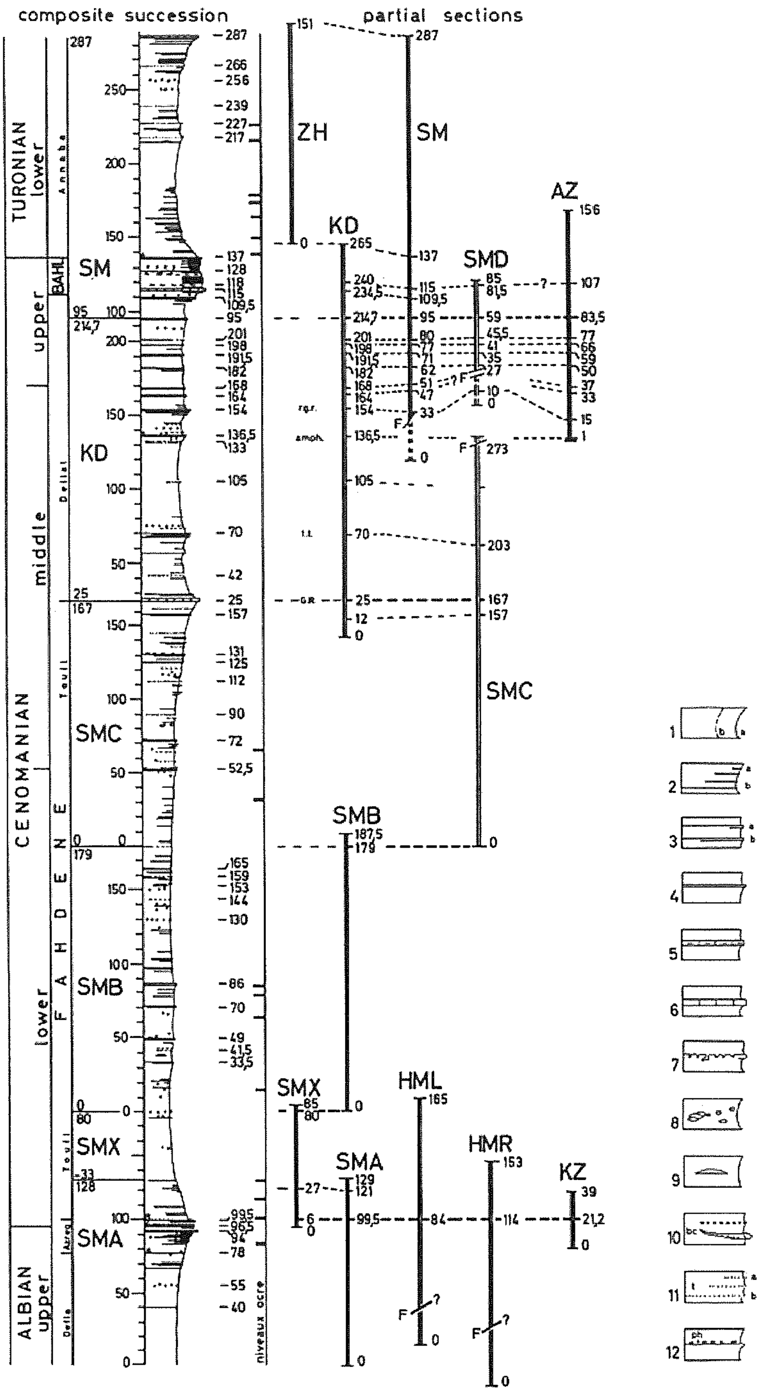


Fig.4 - Composite lithological succession of the Cenomanian of the Kalaat Senan region and position of the partial sections. Legend of the lithological symbols used: 1a, marl; 2a, thin calcareous marl; 2b, thick calcareous marl; 3a, calcareous marl be; 3b, idem., more calcareous; 4-5, successively more calcareous marl; 6, limestones; 7, borings; 8, calcareous septarian nodules; 9, nodular mound or pseudo-bioherm; 10, channelled biocalcarenites and biocalcirudites; 11, tempestites : a, thin, b, thick(5-10 cm); 12, phosphate nodules; G.R., "gros roux bed"; t.l.,"triple large bed" ; amph., "amphibolum bed" ;r.g.r., " triple roux-gris-roux bed".

1. THE ALBIAN-CENOMANIAN BOUNDARY AT THE KEF EL AZREG SECTION (KZ).

The KZ section is situated at about 8 km South East of Jersissa, between wadi El Azreg at the North and Kef el Azreg at the South. Relatively to the lithology, it is a part of the marly Fahdene Formation wich shows, from the bottom to the top; the marly Defla Mb (on 2 m), the Azreg Mb (20m) with alternating grey marls and marly limestone, and the marly Touil Mb (visible on about 17m).

The calcispheric limstones and the marls of the Azreg Mb delivred hundreds of ammonites, especially from *Acanthoceratidae*, *Turrilitidae* and *Lyelliveratidae* families, a lot of individuals of the first familiesbeing preserved in phosphate. Moreover, marls washings ate rich in planktonic foraminifera, especially of *Rotalipora*, *Praeglobotruncana* and *Planomalina* genera.

The vertical distributions of foraminifera and ammonites are given respectively in Fig.5 and fig.6.

The position of the Albian-Cenomanian boundary varied during the last decade.

The Cretaceous Subcomission held its First International Symposium on cretaceous Stage Boundaries at Copenhagen in 1983 (Proceeding in Birkelund et al., 1984). In the preliminary proposals, it was recommended to investigate a definition of the boundary based on the first occurrence of the ammonite species *Hypoturriltes schneegansi* (which co-occurs with species of the genera *Mantelliceras* and *Graysonites*, and which is above the last *Stoliczkaia* and *Mariella bergeri*, two taxa known in the literature asrepresentative of the upper most albian).

In 1993 and 1994, Robaszynski et al., studied the Kef el Azreg section (KZ) and the Samra section (SMA) where is exposed the Albian-Cenomanian transition. Following the Copenhagen recommendations, they polaced the Albian-Cenomanian boundary at KZ19and SMA 96.50, at the level where appear *Hyppoturilites gravesianus*, *Mariella cenomanensis*, *Ostlingoceras rorayense*, *Montelliceras lymense*, *Montelliceras*(now *Graysonites*) *azregensis*, all bioevents just above the extinction of *Stolickaia* sp. And *Mariella bergeri*.

In 1995, a Second International Symposium on Cretaceous Stage Boundaries was held in Brussels (Proceeding in Rawson et al. eds, 1996) during which a proposal was presented to use the first presence of the planktonic foraminifera *Rotalipora globotruncanoides* as the basal boundary criterion for the Cenomanian stage.

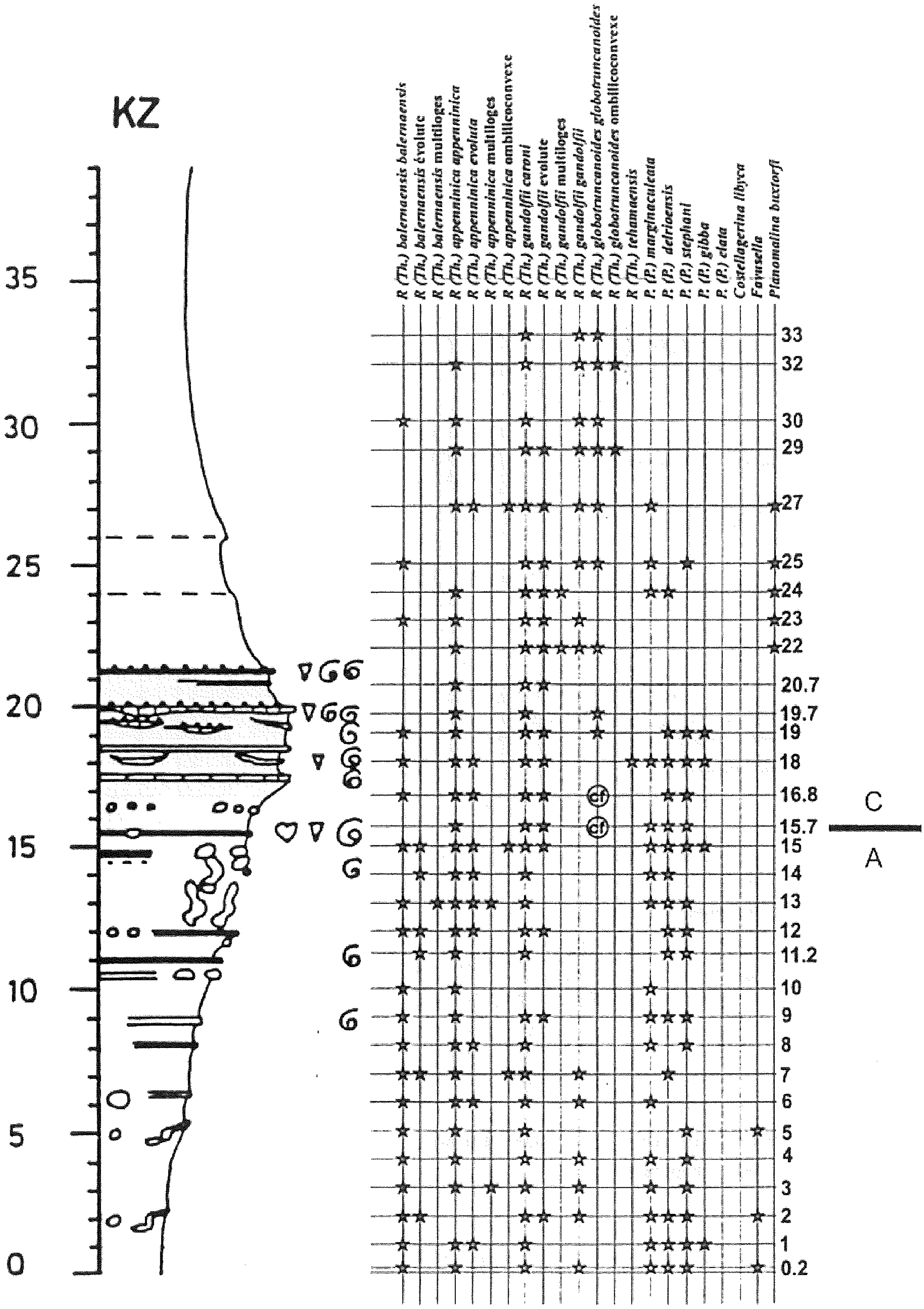


Fig.5- Vertical distribution of planktonic foraminifera in the KD section and tentative position of the Albian-Cenomanian boundary (from Gonzalez Donoso and Linares, work in progress)

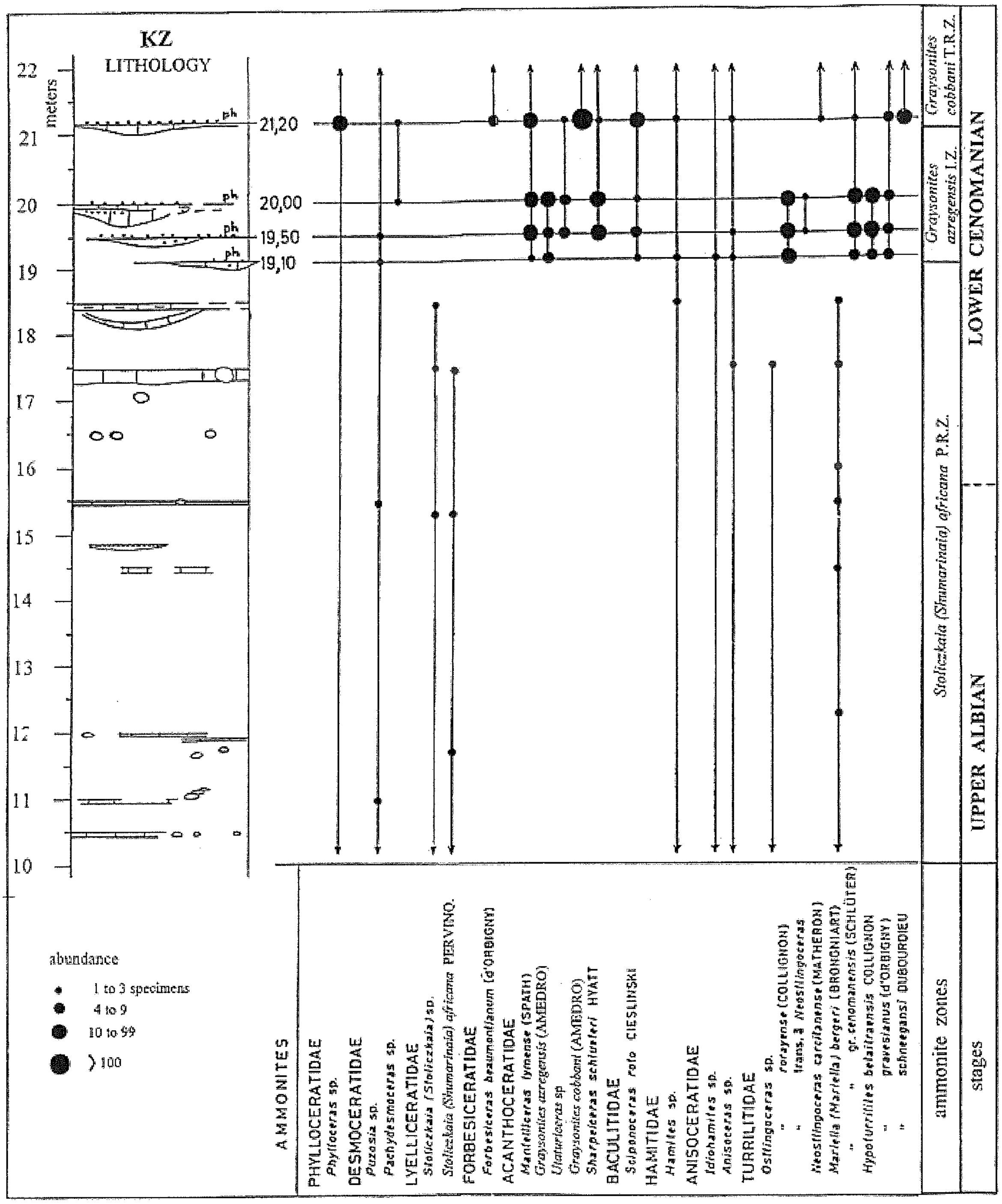


Fig.6- Vertical distribution of main ammonites species in the Kef el Azreg section, KZ (from Amédro, work in progress)

Remark: *Rotalipora brotzeni* SIGAL, 1948(p.102) is considered as a junior synonym of *Rotalipora globotruncanoides* SIGAL, 1948, (p.100); if *Gonzalez donosoand Linares* in Robaszynski et al., 1994.

In Northern Tunisia, the first specimens of *R. globotruncanoides* are noted in Smara section at SMA 92 (4.5 km below the boundary previously given by the ammonite *Montelliceras* at SMa 96.50). In the Kef el Azreg section, intermediate forms of *R. globotruncanoides/R.gondolfii* were found ay KZ 15.7(3.3m below the first *Montelliceras* at KZ19), but true *Rotalipora*

globotruncanoides appears only at KZ 19...that is to say at the same level as the first Mantelliceras.
As there is a gradual evolution from *R.gandolfi* to *R.globotruncanoides,* there is often a difficulty to decide where lies the boundary between the two species and consequently, how and where to place the Albian-Cenomanian boundary.
If the boundary adopted follows what was observed in the sections discussed above, now *Stoliczkaia* and *Mariella bergeri* are present in the basal Cenomanian and Montelliceras is no longer the first appearing Cenomanian ammonite genus.
Moreover, it is to note the presence in the Lower Cenomanian of the last *Planomalina buxtorfi*, a planktonic foraminiferalspecies generally considered as restricted to the upper albian.
Remark: the Cenomanian is the beginning of an important global trangressive pulse, its based is generally marked by a level with phosphates (in Tunisia, in Algeria, in the Paris Basin and also in South-East France, even in the proposed boundary stratotype).

Sequence stratigraphy (Fig.7)
- Below KZ2 (=SMA78-94): HS (highstand system tract) of the precedent sequence.
- KZ2-KZ17.50 (=SMA 78-94): SMW (shelf margin wedge).

The sequence boundary is placed at KZ2((=SMA78) at the level where, in the Smara section, lies a biocalcarenitic bed with a large ammonite *Pachydesmoras* and fragments of bivalves and ammonites, criterions indicating a lowering of the sea level.
The sequence begins in the latest albian and the SMW consists of alternative marls and carbonate beds. These carbonate beds appear channelled and their thickness varies laterally. The entire SMW suggests a slight depositional slope relative to the under-and overlying beds. In this regressive SMW, many species of ammonites and planktonic foraminifera decline. The last bed (KZ17.50=SMA 94) is a massive limestone bed, very calcispheric and contains at the base many fragments of bivalves, echinoids and rudists.

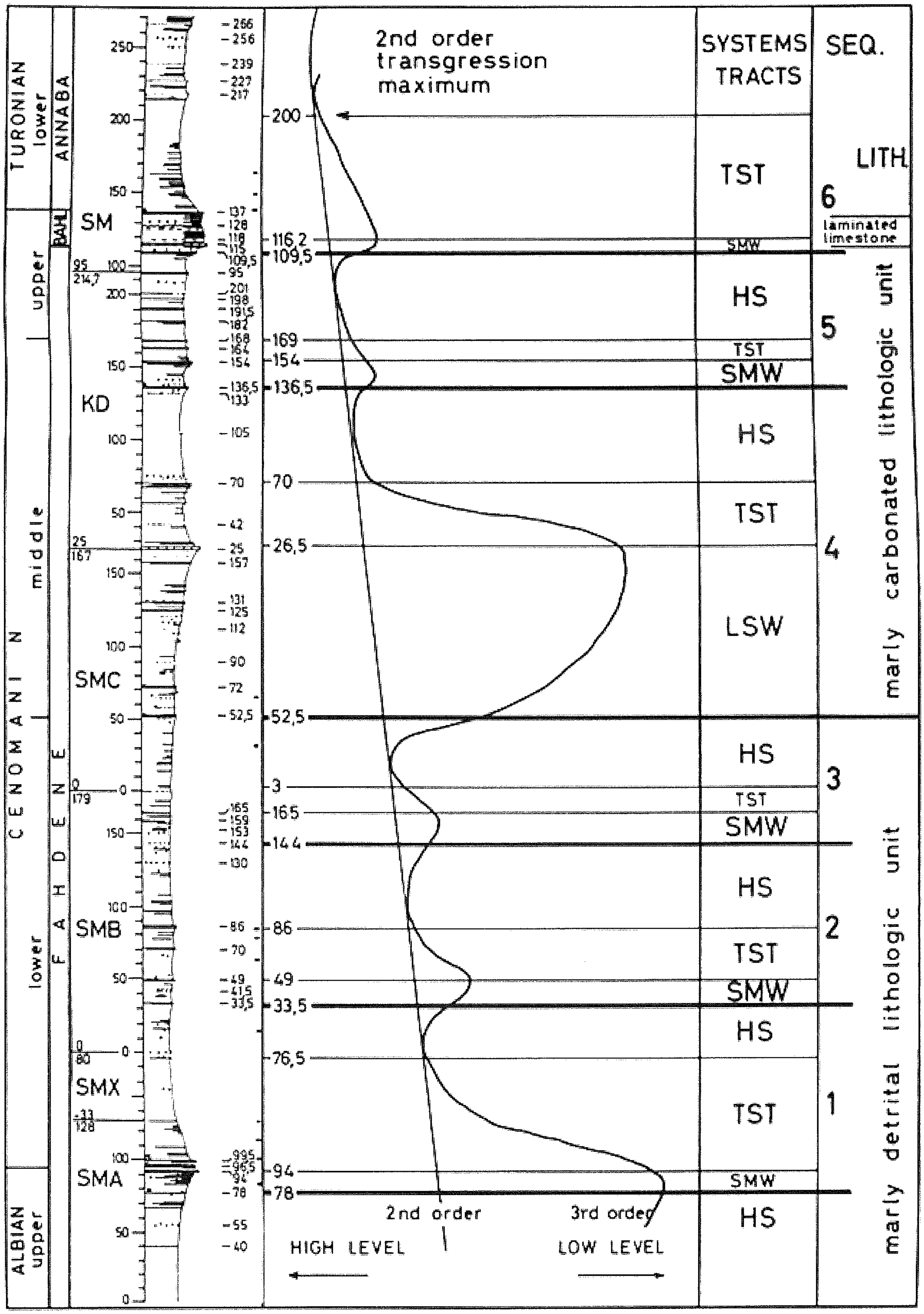


Fig.7- Third and second prder eustatic sea-level variation curve in the Cenomanian of the Kalaat Senan region (after Hardenbol in Robaszynski et *al.,*1993)

- KZ 17.50 and higher up (=above SMA 94) TST (transgressive system tract).

The continuation of the sequence is essentially marly with a thin predominately carbonate section at the base. This carbonate section which contains several phosphatised levels is interpreted as the onset of the TST with a number of coalesced floading surfaces (KZ 19.2-19.5-20-21.20; SMA 96.5-97.5 99.5). The phosphatised contains planispiral andTurrilited ammonites which constitute a new fauna at the Albian-Cenomanian transition.

- Largely above (SMX 76.50), the HS is marly with a few calcareous beds. Its base or DLS (downlap surface) is placed at SMX 76.50 at the first calcareous bed.

2. THE MIDDLE AND UPPER CENOMANIAN AT THE KOUDIAT DELLAL (KD).

Geography The KD section is situated at about 6 Km west of the Kef-Kasserine road and not for from Bir-es-salaa, between the small wadi Hammdja and wadi Zitoune. (Fig.8).

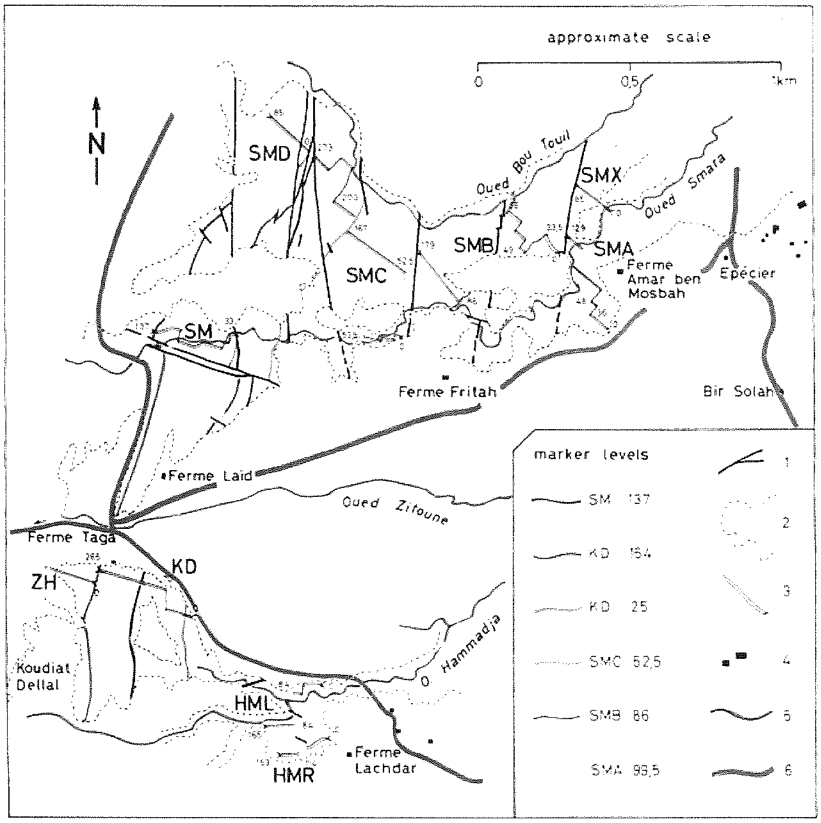


Fig.8- Location of the sections in the Cenomanian of the Kalaat Senan region. 1:fault; 2:limit of the Quaternary cover; 3:sections; 4:farms; 5:wadi; 6:car track

Lithology It consists marls interbedded with limstones. The Fig.9 propose a detailed lithological succession of the KD section with the position of the main and secondary limestones beds, of calcarenite tempestite levels and of macrofossils collected fragments (cf.Burrolet 2 Robaszynsky, 1991).

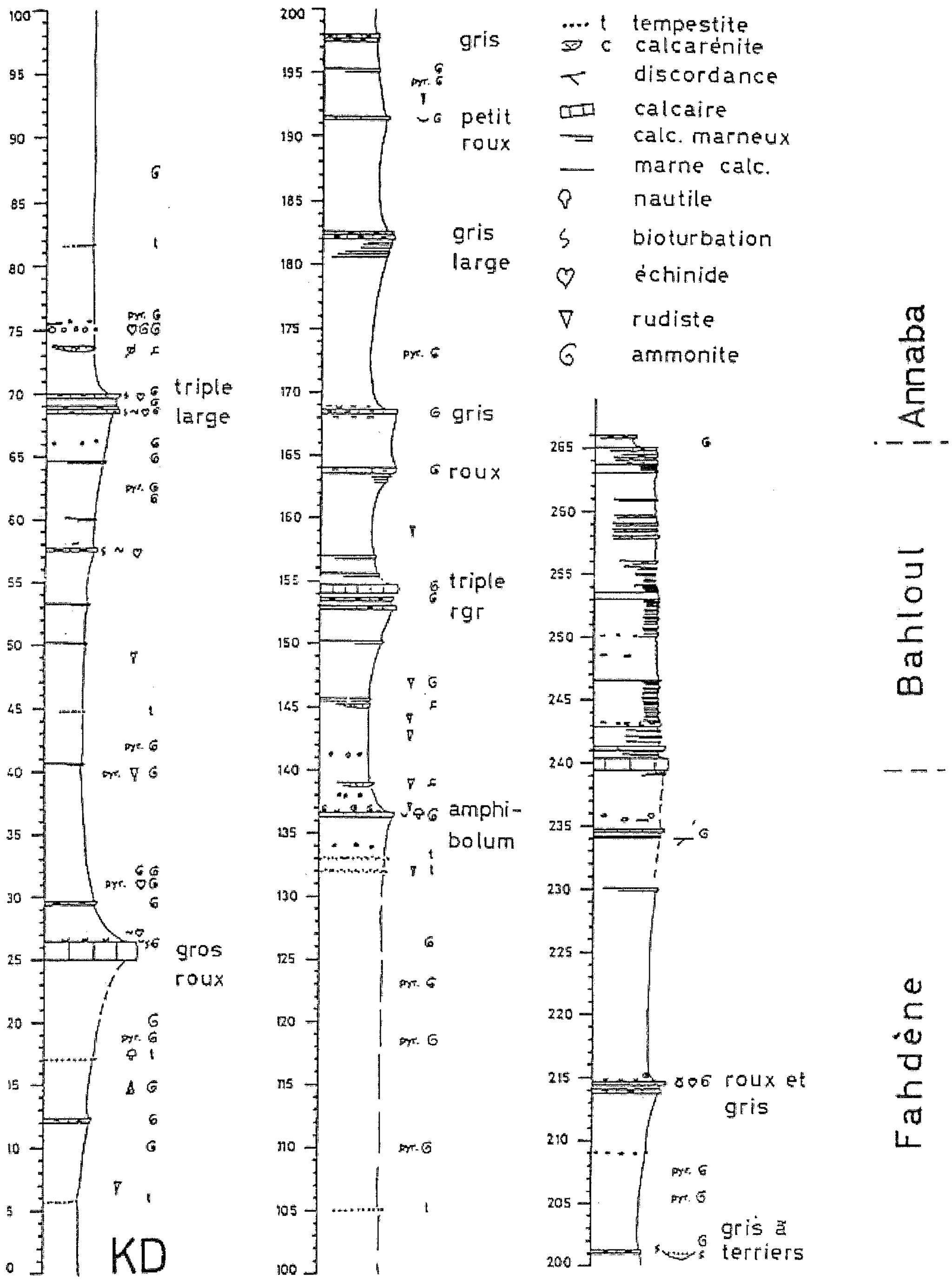


Fig.9- The KD section: lithologic succession in the Middle-Upper Cenomanian of the Koudiat Dellal area

Paleontology

Ammonites (Fig.10) *Acanthoceras* cf. *rhotomagense* and *A.amphibolum* (Middle Cenomanian) are present in the greates part of the KD section up to KD 170. *Paraconlinoceras* aff. *barcusi* was found at KD 74. *Eucalycoceras pentagonum* appears at KD 164 and *Eucaycoceras* spp. Continue in the Upper Cenomanian.

With other species of ammonites found in the SM section, seven zones are defined in the Middle-Upper Cenomanian:

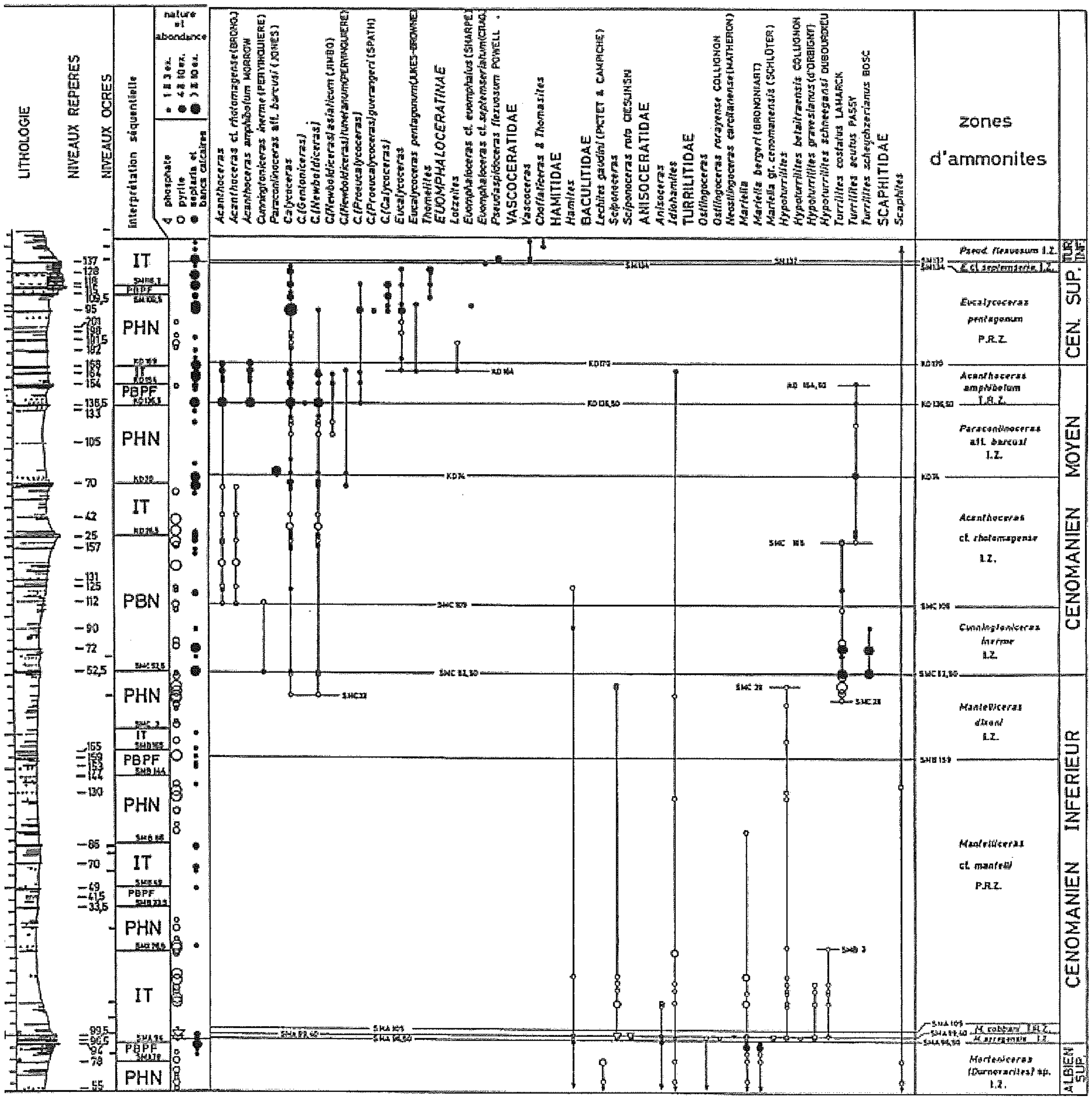


Fig.10- The Middle-Upper Cenomanian ammonites in the KD section (Koudiat Dellal area). From Amédro in Robaszynski et *al.*,1994

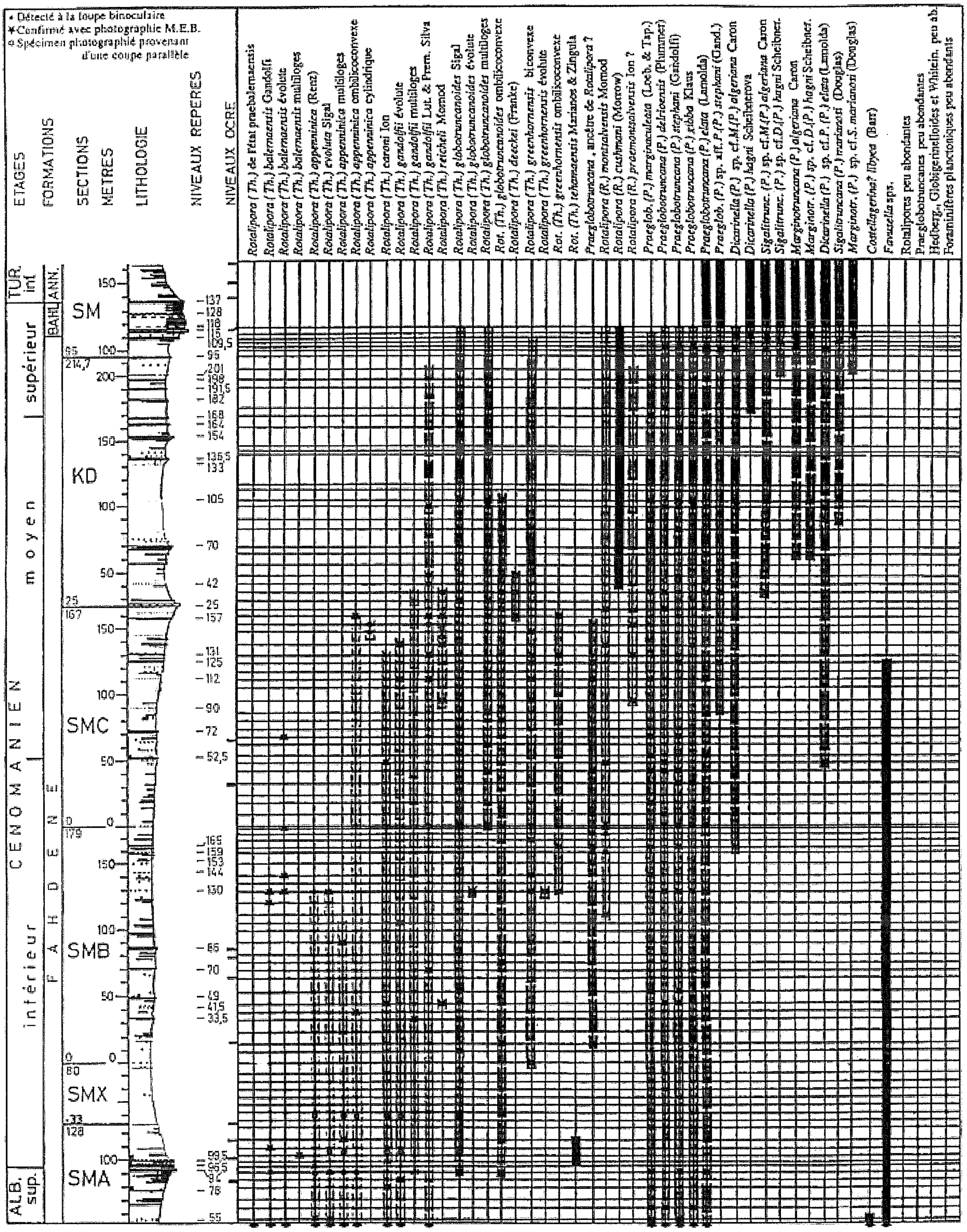


Fig.11- Vertical distribution of planktonic foraminifera in the Cenomanian of the Kalaat Senan area (after Gonzalez Donoso et Linares in Robaszynski et *al.*,1993)

Upper Cenomanian	*Pseudaspidoceras pseudonodosoides* zone *Metoicoceras geslinianum zone* (correlative) *Eucalycoceras pentagonum* zone	
		KD 170
Middle Cenomanian	*Acanthoceras amphibolum* zone *Paraconlinoceras aff.barcusi* zone *Acanthoceras cf.rhotomagense* zone *Cunningtoniceras inerme* zone	

Remark: numerous ammonites genera as *Cunningtoniceras*, *Acanthoceras,Clyoceras, Metoicoceras, Turrilitidae,* ect are in common with the Boreal domain, but several ammonites faunas are cited for the first time in Tunisia and were known until now only in the Western Interior of the USA such as *Paraconlinoceras aff barcusi* and *Acanthoceras amphibilum* planktonic foraminifera (Fig.11). From the main species *Rotalipora reicheli* extinct at KD 35. *R.deeckei* is present in the KD 15-48 interval. *R.cushmani* appears at KD 90 and *Dicarinella kangui* at KD 174.

These index species are associated with *R.globotruncanoides*, *R.greenhonensis*, *R. montsalvensis*, *Praeglobotruncana delrioensis*, *P. stephani*, *gibba*, *elata*, *Dicarinella algeriana.*

Sequence stratigraphy in the KD section (Fig.12)

The succession was deposited in a basin margin setting (after Hardenbol et *al*., 1993).

The middle Cenomanian section is well developed and over 200m thick. The upper Cenomanian is about 100m thick. Long term (second order) sea level rose rapidly during the Middle and Late Cenomanian, albeit interrupted by two relatively small falls, and reached its maximum in the earliest Turonian. The organic rich transgressive deposits in the Bahloul formation was deposited when both short term and long term rose rapidly. The resulting major transgression of lowlands areas may have contributed to the triggering of a preoductivity event of widespread occurrence of organic-rich deposits in basinal settings during the latest Cenomanian and earliest Turonian.

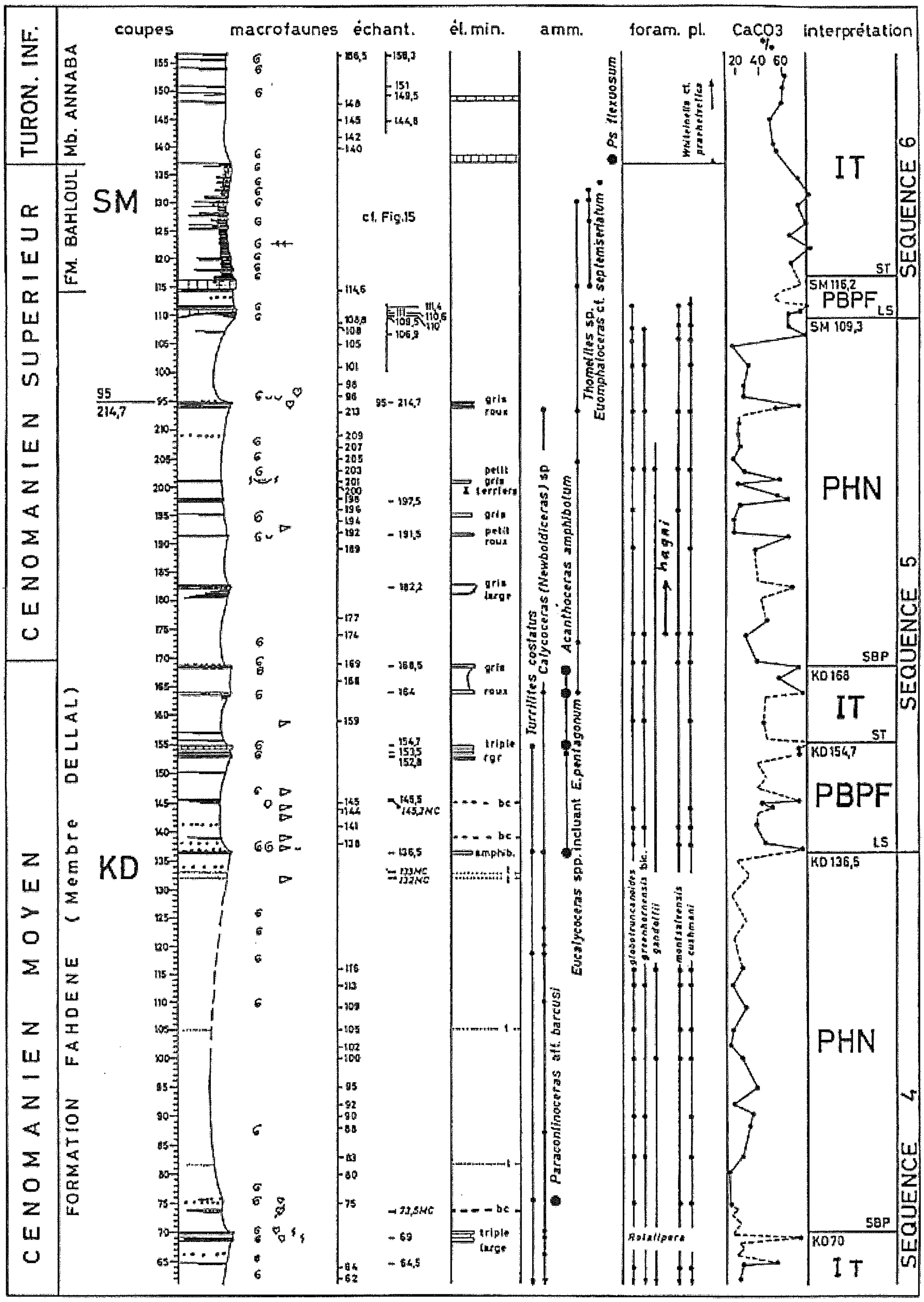


Fig.12- Lithology, bioevents and sequence stratigraphy in the Middle to Upper Cenomanian in the KD and SM sections of the Kalaat Senan area.

The base of the KD section (0-25 m) consists of marls with thin detrial limestone beds and two 1-2 cm thick tempestits containing quartz grain. The deposits in this interval is interpreted as the upper part of an aggrading lowstand wedge because of an increase in pelagic characteristics (common *Rotalipora* for example) relative to the underlying section. The two tempestits are thinner than the tempests in the lower part of the lowstand wedge (below the KD section). The transgressive surface is tentatively placed at the upper surface of a prominent limestone bed (KD 25). This 1.5 m thick limestone bed represents a major accumulation of calcispheres deposited at the time of initial flooding when terrigenous material became trapped in drowning estuaries and calcispheres bloomed at the platform margin. The presence of planktonic foraminifera in the limestone supports the transgressive interpretation. The overlying transgressive deposits consist the mostly of marls with several thin marly limestones beds. The downlap is placed at the prominent detrial limestone bed (KD 70) which is marlier than bed KD 25 and contains fewer calcispheres and planktonic foraminifera.

The overlying predominantly muddy deposits represent the basinal equivalent of prograding highstand deposits.

The next sequence boundary (KD 136.50) marks the return of more frequent intercalated limestones beds. The top of the thin and detrial shelf margin wedge is placed at the top of prominent limestone bed (KD 154). The increase in the number of planktonic foraminifera of genus Rotalipora above KD 154 supports the overall transgressive nature of the deposits.

The downlap surface is tentatively placed at the top of a predominately limestone bed (KD 168). Above this bed the number of pelagic taxa such as *Rotalipora* and micromolluscs ("filaments") as seen in thin section, decrease markedly in the subsequent detrial limestone beds.

The last sequence boundary in the Cenomanian (KD 234) marks the sudden return of detrial limestone deposited in a thin shelf margin wedge topped by a thick prominent detrial limestone bed (KD 240)which forms the boundary between the Fahdene formation and the Bahloul formation. The transgressive deposits in the uppermost Cenomanian Bahloul formation are characterized by there high organic matter content. The presence of organic-rich facies near the Cenomanian-Turonian boundary is a widly reconized phenomen and extensively cited in the literature. The anoxic deposits in the Kalaat Senan area are essentially restricted to the uppermost Cenomanian-Lowest Turonian.

3. THE CENOMANIAN-TURONIAN BOUNDARY IN THE BAHLOUL FORMATION AT THE SMARA SECTION (SM).

3.1 The base of the Turonian stage in Tunisia since the twentieth century (Fig.13)

In 1903, Pervinquière confers to his "marnes schisteuses" (the future Bahloul formation) a Turonian age, but without paleontological evidence.

I, 1956, Burrolet follows this interpretation and places the base of the Turonian at the base of his Bahloul formation.

In 1990, Robasczynski et *al.*, follow the recommendation of the First Symposium on Cretaceous stage Boundary (Birkelund et *al.*,1984) and place the base of Turonian at the first appearance of *Pseudaspidoceras flexuosum* which is at the top of the Bahloul formation.

Then, Maamouri et *al.*, (1994) and Ben Haj Ali et *al.*, (1994) use the first occurence of respectively, planktonic foraminifera and ammonites (*Fagesia*) low then high in the Bahloul formation for placing the Cenomanian-Turonian (C/T) boundary.

In 1996 and 2000, Accarie et *al.*, study the position of carbon isotope events, and their "event II", considered as the C/T boundary, lies in about the middle of the Bahloul formation.

More recently, Amedro et *al.*, (in press) follow the new recommendations of The Second Symposium on Cretaceous stage Boundaries (Rawson et *al.* eds, 1996) and use the appearance of *Watinoceras* sp for the base of the Turonian at the SM 128.20 (same level as the appearance of *Fagesia* of Ben Haj Ali et al., 1994).

3.2 Ammonite zonation

The evolution of the ammonite zonation for the upper Cenomanain and Lower Turonian since 1983 is presented in the Fig.14.

3.3 The SM section

The section is located in Fig.8. It follows the Wadi Smara and exposed completely the upper part of the Fahdene formation, the entire Bahloul formation and overlying Annaba and Bireno Members.

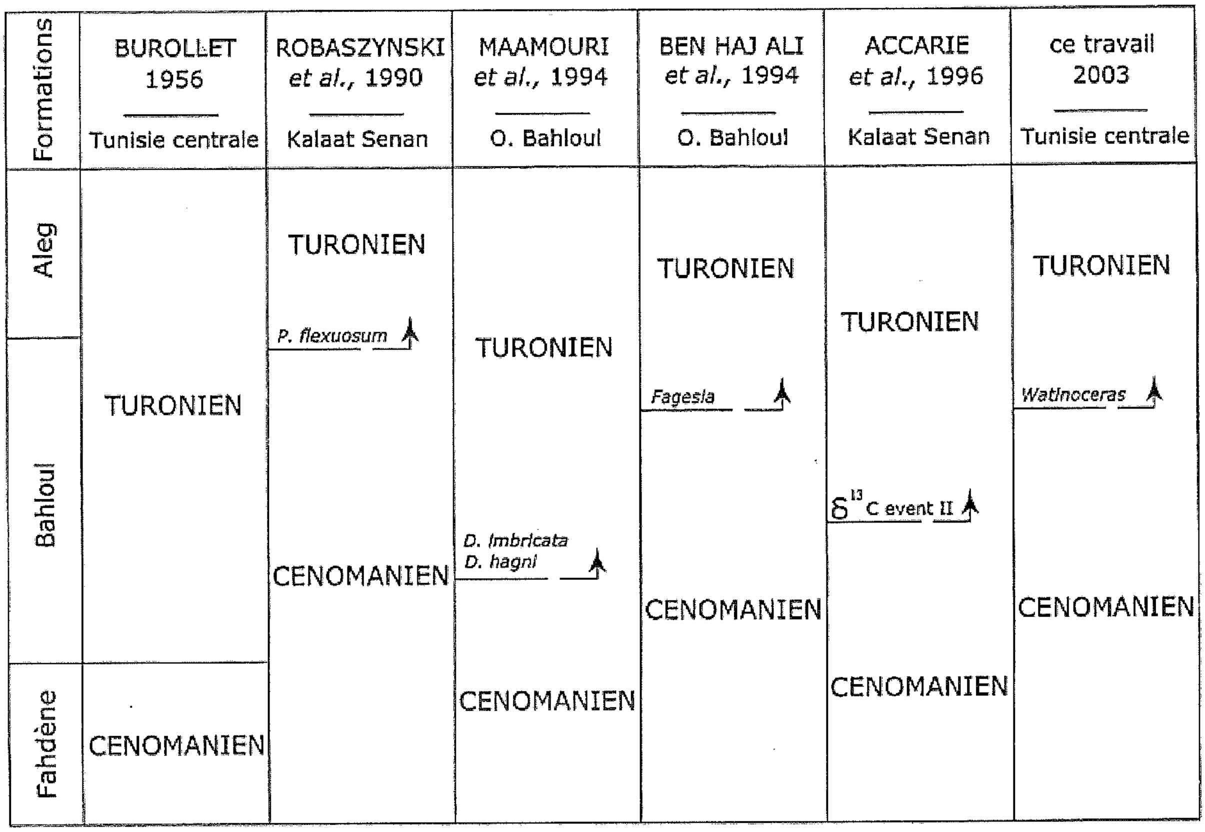


Fig.13- The position of the Cenomanian-Turonian boundary in Tunisia since Burrolet t (1956) who follow Pervinquière (1903).

Lithology

<table>
<tr><th>Copenhague
1983</th><th>ROBASZYNSKI
et al., 1990</th><th>ROBASZYNSKI
et al., 1993, 1994</th><th>CHANCELLOR
et al., 1994</th><th>Bruxelles
1995</th><th>ce travail
2004</th></tr>
<tr><td>TUR. INF.
P. flexuosum</td><td>Pseudaspidoceras flexuosum</td><td>Pseudaspidoceras flexuosum</td><td>Pseudaspidoceras flexuosum</td><td rowspan="2">TURONIEN
INFERIEUR
W. devonense</td><td>Pseudaspidoceras flexuosum</td></tr>
<tr><td rowspan="4">CENOMANIEN
SUPERIEUR</td><td>(non reconnu)</td><td>(non reconnu)</td><td>(non reconnu)</td><td>Watinoceras sp.</td></tr>
<tr><td>(non reconnu)</td><td>Pseudaspidoceras pseudonodosoides</td><td>Pseudaspidoceras pseudonodosoides</td><td rowspan="3">CENOMANIEN
SUPERIEUR</td><td>Pseudaspidoceras pseudonodosoides</td></tr>
<tr><td>Euomphaloceras cf. septemseriatum</td><td>Euomphaloceras cf. septemseriatum</td><td>(non reconnu)</td><td>Metoicoceras geslinianum</td></tr>
<tr><td>Eucalycoceras sp.</td><td>Eucalycoceras pentagonum</td><td>niveaux à
Calyco. haugi et
Calyco. guerangeri</td><td>Eucalycoceras pentagonum</td></tr>
</table>

Fig.14- Cenomanian-Turonian boundary and ammonite zones (from Amédro et *al*., in press)

The Fig.15 shows the lithological succession of the Bahloul formation, between the marls and the limestone beds of the Fahdene formation and the marls of the Annaba MB above. From bottom to the top, three units can be distinguished:

SM114.10-SM 118: "pre-bahloul". Interbedded limestones and marls with the first laminated black-shales at the base wich are indicative of the onset of anoxic conditions. From 114.6 to 116.2, a massive limestone bed consists of a rich calcisphere limestone with several small slumpings in the middle. Above, follows a succession of decimetric grey limestone beds slightly laminated.

SM118-SM129: typically Bahloul facies black and finely laminated with several small slumping (116.7; 118), pyretic nodules (126.3; 127) and flattened bioturbations everywhere.

SM 129-SM137: laminated black limestones (2-4dm) alternating with marly grey limestones.

Microfacies

Typically, the microfacies of black laminated Bahloul facies shows dark laminae representing the continuous sedimentation of the organic rich matter forming the matrix and light coloured laminae indicating successive microplankton blooms of calcisphere, followed by *Heterohelicides* and lastly *Whiteinellids*.

Palaeontology

Ammonites: Redetermination of numerous ammonites collected since 1985 and new collecting in the SM section are presented in Fig.15. The most important informations are given from the appearance of *Fagesia sp*. At SM 128.20 and *Watoniceras sp*. Just above, two taxa indicating a Turonian age. These first Turonian ammonites at SM 128.20 are very close to the end of the very finely laminated unit of the Bahloul formation (SM 129) and to the first "filaments" found in the microfacies at SM 127.50.

Planktonic foraminifera: the last presence of *Rotaipora cushmani* is noted at SM 114.7, at the base of the thick limestone bed of the pre-Bahloul unit. In the black laminated facies of the Bahloul formation, keeled planktonic foraminifera are absent or extremely rare, but *Whiteinellids* are generally present in great numbers and are visible under the microscope in the light coloured laminae.

In the upper lithological unit of the Bahloul formation 5between SM 129 and 137), in addition to *Whiteinellids,* several thin sections demonstrated the presence of forms with a flattened spiral side close to *Whiteinella praehelvetica.*

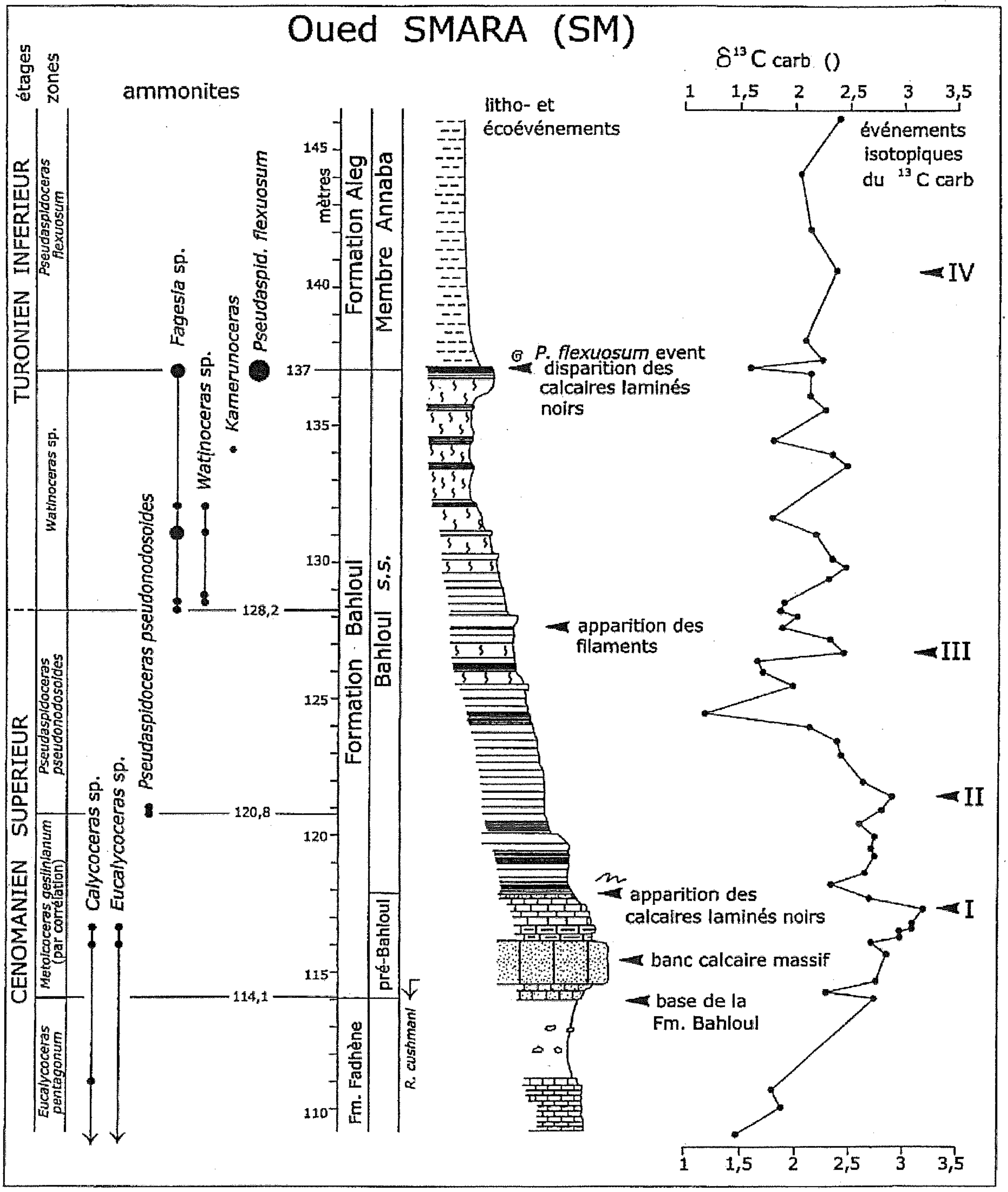


Fig.15- Bahloul Formation, Cenomanian-Turonian boundary, ammonites and dC13 curve in the wadi Smara, SM section (from Amédro et *al.*, in press)

Sequence startigraphy: (Fig.16)

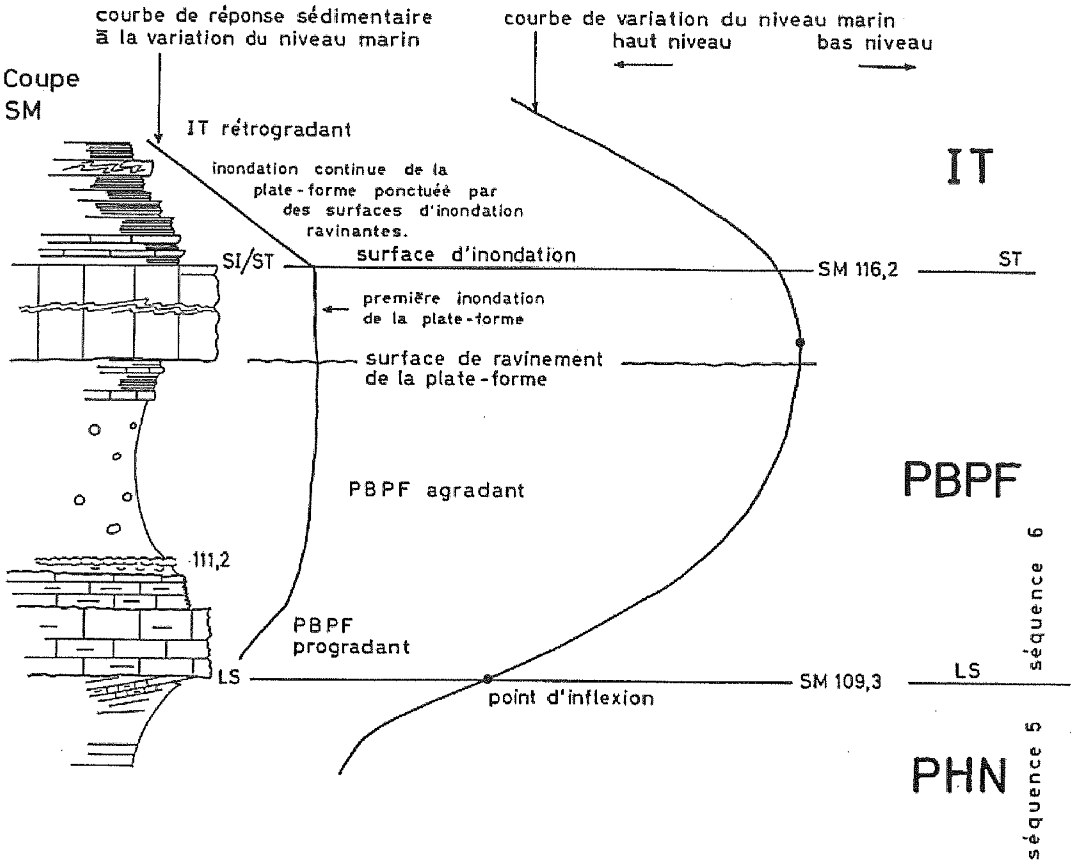


Fig.16- Tentative correspondence between sedimentation and relative sea-level variation in the Upper Cenonamian of the Kalaat Senan area (after Hardenbol *in* Robaszynski et *al.,*1994)

SM109-SM116.2: SMW (Shelf Margin Wedge). The marly limestone beds at the base overlie, with a slight sub-sea erosional unconformity, the preceding highstand levels. Their thickness decrease laterally, which suggests deposition in major channel-like structures. The surface of the limestone beds contain bivalves fragments. Overlying these limestones are marls followed by thick grey calcispheric limestone bed, affected by synsedimentary slumping. These features indicate a higher rate of deposition platform drived material on an unstable slope. Hence the SMW interpretation.

SM116.2-SM200: Transgressive system tract. The interval includes the Bahloul formation where the black laminae show tubular bioturbations flattened by compaction which contain glauconite and phosphate grains. The Bahloul formation contains organic matter (TOC of 1 to 2.2%) but the alternation of dark beds rich in organic matter with light beds of calcispheres and planktonic foraminifera implies a klong period of alternating anoxic and dysareobic environments especially during the lates Cenomanian.

From the transgressive surface on SM 116.2, all the overlying black laminites are included in a TST. The SM137 level at the top of Bahloul formation is interpreted as a flooding surface towards the end of the major transgressive episode which began in thez latest Cenomanian and continued until the maximum flooding surface in the Lower Turonian (SM200=downlap surface), cf. Robasczynski et *al.,*1990).

Duration of anoxic event (Bahloul formation), Caron et al., 1999

A tentative measurement of the duration of the OAE was made in the wadi Bahloul wher the 29 m of the formation show a regular repetition of a sequence of black laminated limestone and bioturbated grey marls.

The black laminated limestones are characterized by abundant faecal pellets and poorly diversified planktonic. By contrast, the grey bioturbated marls show occasional benthic forms (buliminellides) and diversified planktonic foraminifera. The laminated limestones contain abundant amorphous erganic matter while palynomorphs occur more commonly in the grey marls.

A multi-parametric analysis (texture, bioturbations, microbotas, COT, CaCO3, coccoliths, clay-minerals) indicates deposition in a semi-confined marine basin strongly influenced by thermohaline oceanic circulation depending mainly on climatic fluctuations: the blackj limestones were deposited under anoxic conditions while the grey marls reflect et least temporarely oxygenated environments.

Each lithological cycle reflects short-term climatic fluctuations: arid conditions are associated with the black limestones whereas the grey marls correspond to sub-humid conditions. These environmental changes are interpreted as being related to precession cycles of 20000 years. According to the number of precession cycles identified in the Bahloul section, the Bahloul formation probably was deposited during one eccentricity cycle of 400 000 years. This cyclostratigraphic interpretation, calibrated by biostratigraphy, constrains the duration of the anoxic event more precisely than radiometric ages which suggested a duration comprised between 100 and 900 Ky (500 ± 400ky).

Correlation (Fig.17)

Using several kinds of events: bioevents as entries or last occurrences of ammonites and planktonic foraminifera, appearance of “filaments”, geochemical events as □C^{13} excursions I to IV…a tentative of correlation was made for three sections of the Bahloul formation (wadi Smara=SM section, Kef el Azreg section-about 20km East of SM and wadi Bahloul section-type Bahloul area, about 50 km East of Kef el Azreg).

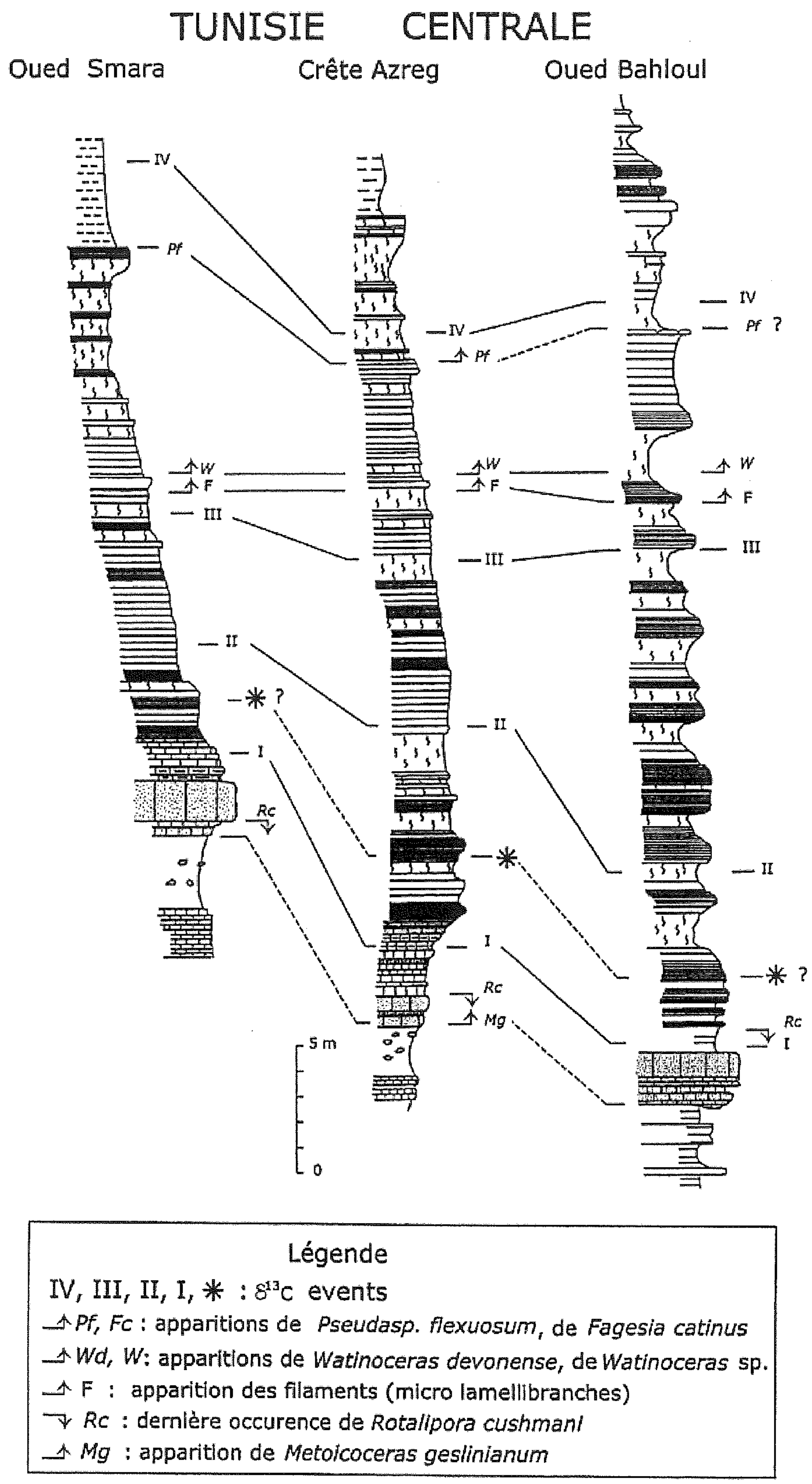


Fig.17 - Tentative correspondence between sedimentation and relative sea-level variation in the Upper Cenomanian of Kalaat Senan area.

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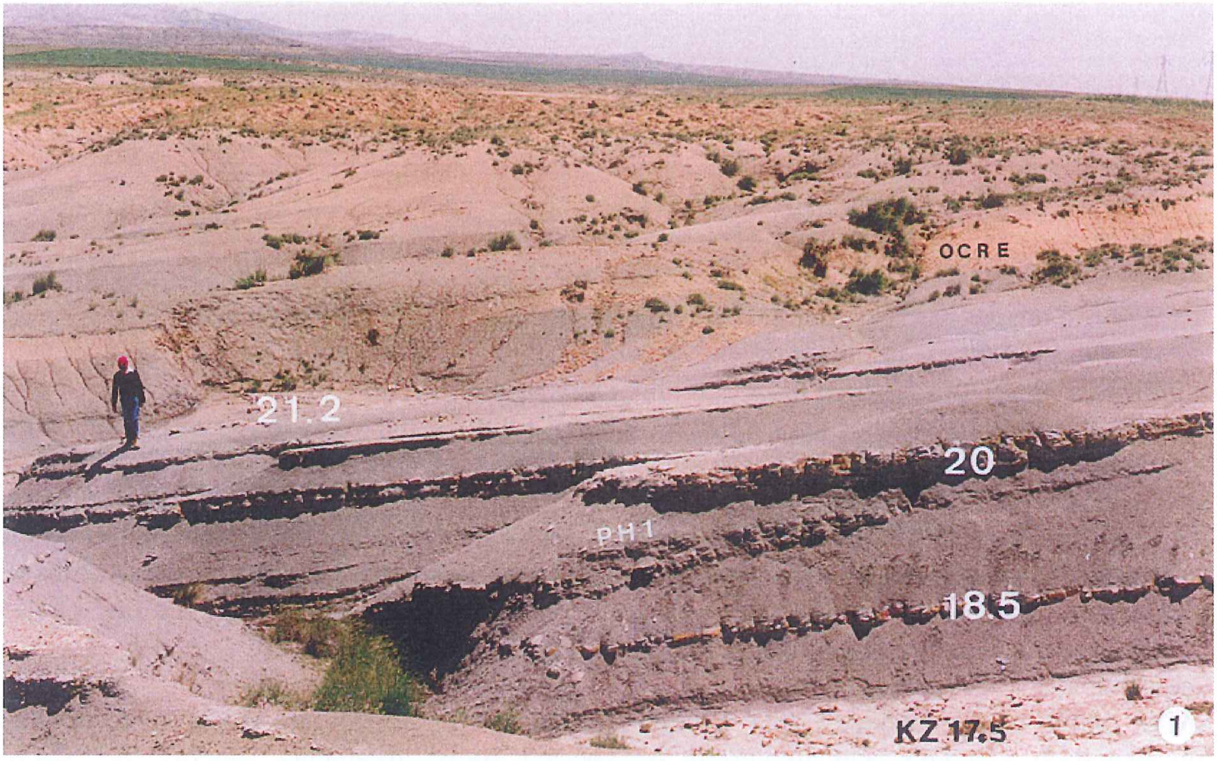
Planche 1

Photo 1- KZ section at Kef el Azreg
The slight dip and the differential erosion of the marly limestones and the grey result in a good exposure of the beds just above tne Cenomanian-Turonian boundary which is situated at about KZ 15.7. A number of the marly limestones are channelled (KZ 18.5, 19.5, 20, 21.2…). In the picture, the first phosphate nodule bed (ph 1) at KZ 19.50 is not well developed, but to the left two separate levels can be distinguished.
As the Cenomanian-Turonian boundary is defined at about KZ 15.7 by the first presence of *Rotalipora* close to globotruncanoides, the last *Stoliczkaia dispar* and *Mariella bergeri* collected at KZ 17.50 and KZ18.50 are now lowest Cenomanian in age. Moreover, the first ammonite species of the genera *Mantelliceras* and *Hypoturrilites* at KZ 19.50 do not indicate now the basal Cenomanian.
Photo 2- KZ section at Kef el Azreg
Between KZ 15.5 and 17.5 are grey marls where, at KZ 15.7 and 16.7, were found the first planktonic foraminifera which morphology is close to *Rotalipora globotruncanoides* and indicating the base of the Cenomanian (they are intermediate forms between *R. gandolfi* and *R.globotruncanoides*)


OCRE
21.2
20
PH1
18.5
KZ 17.5
1


17.5
KZ 15.5
2

Planche 2

Middle and upper Cenomanian in the Koudiat Dellal section (KD)
Photoc1- Panoramic view of the sequences 4.5 and 6 (cf.fig. 7). View to the North; the stike is roughly N-S with a dip of 20-35° to the West (at left)
Sequence 4
HS (high stand), KD 70-136, 50: this systems tract contains ammonites previously known only in the Western Interior of the USA (*P. barcusi* and *A.amphibolum*). the presence of these immigrants suggests the establishment of major oceanic connections toward the end of the Middle Cenomanian as a result of a major eustatic rise.
Sequence 5
SMW (shelf margin wedge), KD 136.50-154: wedge of calcareous marls with several biocalcarenite channels and numerous transported rudist fragments support the SMW interpretation. *Turrilites costatus* becomes extinct.
TST (transgressive system tract), KD 154-168: brief episode characterized by the common occurrence of *A. amphibolum.*
HS (highstand), KD 168-234=SM109.3: wedge of 60 m of marls and limestone beds topped by somewhat channelled marly limestone sequence.
Sequence 6
SMW (shelf margin wedge): KD 234-240=SM 116.2: succession of channelled marly limestone marls and grey limestones with small synsedimentary slump features.
TST(transgressive system tract): above KD 240: black laminated limestone of the Bahloul Formation weathered to a light grey.
Photo 2: KD25-26.5: calcipheric limestone bed, "gros roux", base of the sequence 4 TST; KD 42: tempestite; KD 68-70 "triple large": downlap surface.
Photo 3: KD 136.50: *amphibolum* bed, base of the sequence 5; 154 "triplergr"; between 136.50 and 154 are two biocalcarenitic channels of a few cm thick.
Photo4:
KD 155: top of the "triple rgr", transgressive surface.

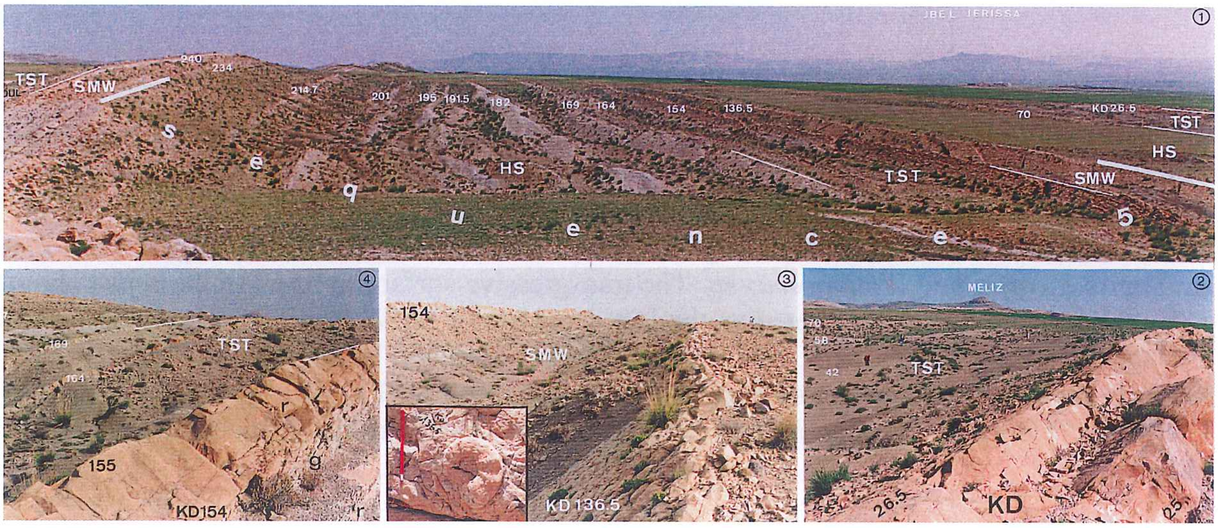

JBEL IFRISSA
1
TST
SMW
240
234
214.7
201
196
191.5
182
169
164
154
136.5
70
KD 26.5
TST
HS
HS
TST
SMW
s
é
q
u
e
n
c
e
5
4
169
TST
161
155
KD154
g
r
3
154
SMW
KD 136.5
2
MELIZ
70
58
42
TST
26.5
KD

Planche 3

The Bahloul Formation at wadi Smara (SM section) uppermost Cenomanian to lowest Turonian

The Cenomùanian-Turonian boundary is placed at SM 128.20 where appear the first ammonite *Fagesia* and *Watinoceras* sp. The transgressive surface at SM 116.20 is just above a thick clacisphreic bed interpreted as the last deposit of a SMW (shelf margin wedge). The laminated Bahloul facies as a part of the Annaba Member belong to the Transgressive Systems tract with numerous flooding surfaces as SM 120, 128, 137…
The first "filaments" appear around SM 128, very close to the Cenomanian-Turonian boundary.


Planche III
287
Bireno
Annaba
128
IT
SM 116,2
ST
Bahloul
PBPF
114
SM 109,3
LS
PHN
Fahdène